NR

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 18 December 2000 (18.12.00)	
International application No. PCT/CA99/00290	**Applicant's or agent's file reference** 14074-1PCT
International filing date (day/month/year) 01 April 1999 (01.04.99)	**Priority date** (day/month/year)
Applicant DUBE, Jean-Yves et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

26 October 2000 (26.10.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Claudio Borton

Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

PCT

To:

SWABEY OGILVY RENAULT
1981 McGill College Avenue
Suite 1600
Montréal, Québec H3A 2Y3
CANADA

NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of mailing *(day/month/year)*	10.07.01

Applicant's or agent's file reference	IMPORTANT NOTIFICATION
14074-1PCT GH	

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/CA 99/00290	01/04/1999	

Applicant

DUBE, Jean-Yves

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices)(Article 39(1))(see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Paola Ottaviani

EUROPÄISCHES PATENTAMT · EUROPEAN PATENT OFFICE · OFFICE EUROPÉEN DES BREVETS

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
14074-1PCT		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/CA 99/00290	01/04/1999	
International Patent Classification (IPC) or national classification and IPC		
H02K21/22		
Applicant		
DUBE, Jean-Yves		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This **REPORT** consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consists of a total of 10 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☒ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
26/10/2000	10.07.01
Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	P. Le Guay

EUROPÄISCHES PATENTAMT - EUROPEAN PATENT OFFICE - OFFICE EUROPÉEN DES BREVETS

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/CA99/00290

I. Basis of the report

1. This report has been drawn up on the basis of *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.)*

☐ the international application as originally filed

☒	the description, pages	1-3, 5, 6, 8, 11, 12	, as originally filed	
	pages		, filed with the demand	
	pages	4, 4a, 7, 9, 10	, filed with the letter of	16.05.01
☒	the claims, Nos.		, as originally filed	
	Nos.		, as amended under Article 19	
	Nos.		, filed with the demand	
	Nos.	1-10	, filed with the letter of	16.05.01
☒	the drawings, sheets / fig.	3/10-10/10	, as originally filed	
	sheets / fig.		, filed with the demand	
	sheets / fig.	1/10-2/10	, filed with the letter of	16.05.01

2. The amendments have resulted in the cancellation of:

☐ the description, pages:

☐ the claims, Nos.

☐ the drawings, sheets / fig.

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2 (c)).

4. Additional observations, if necessary:

IV. Lack of unity of invention

1. In response to the invitation (Form PCT/IPEA/405) to restrict or pay additional fees the applicant has:

- ☐ restricted the claims.
- ☐ paid additional fees.
- ☐ paid additional fees under protest.
- ☒ neither restricted nor paid additional fees.

2. ☐ This Authority found that the requirement of unity of invention is not complied with and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

- ☐ complied with.
- ☒ not complied with for the following reasons:

1. The separate inventions/groups of invention are:

   a. a brushless DC motor wound with one coil per slot (Claim 1)
   b. a brushless DC motor wound with two coils per slot (Claim 2)

2. They are not so linked as to form a single general inventive concept (Rule 13.1 PCT) for the following reasons:

   The common subject-matter between the two groups of claims is known and acknowledged to be known. Thus, said common subject-matter is limited to the preamble of Claims 1 and 2. On the other hand, there is no common relevant feature between the characterizing part of Claim 1 and the one of Claim 2.

   Therefore, there is a lack of unity of invention between Claim 1 and Claim 2.

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

- ☐ all parts.
- ☒ the parts relating to claims Nos. 1, 3-10

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Claims	1, 3-10	YES
	Claims	None	NO
Inventive Step	Claims	1, 3-10	YES
	Claims	None	NO
Industrial Applicability	Claims	1, 3-10	YES
	Claims	None	NO

2. Citations and Explanations

1. Concerning Claim 1:

a. Claim 1 relates to a brushless DC motor/generator having a 22-pole rotor, a 24-slot stator and an electronic supply;

b. nearest prior art is document GB-A-2 289 991 which discloses such a machine;

c. the claimed machine additionally discloses a specific predetermined connection pattern;

d. the purpose of this specific pattern is to reduce the torque ripple of the machine;

e. this additional feature is new and inventive with respect to the available prior art as none of the cited documents discloses or suggests such a pattern;

f. therefore, Claim 1 complies with the requirements of Article 33(2) and (3) PCT.

2. Concerning Claims 3 to 10:

These depending claims disclose particular embodiments of the invention. Therefore, they have to be considered as novel and inventive in terms of Article 33(2) and (3) PCT.

3. The industrial applicability of the motor according to Claims 1 and 3 to 10 is obvious.

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

1. Claim 3 is not consistent with Claims 1 and 2 from which it depends.

   Thus Claims 1 and 2 disclose a motor with twenty-two poles and twenty-four slots. Claim 3, on the contrary, discloses different numbers of poles and slots. Like (44, 48), (66, 72) and (96,88).

2. Claim 5 lacks clarity in terms of Article 6 PCT.

   This claim discloses a modulation driver (30) while reference number 30 has been used for push-pulls in the description and the figures (see page 9 and figure 6).

   Moreover, Claim 5 discloses "said current control (32)" although such a current control has not yet been evoked.

3. The same applies for Claim 9 which discloses "power mosfets (30)".

Reference is made to British Patent GB 2 289 991 which discloses a winding sequence for a motor having twelve slots and ten poles. It is described in that Patent the use of a specific rotor structure and a specific winding sequence wherein one winding per slot is provided to obtain independent magnetic flux flow for each phase.

Japanese Patent A-400 4703 relates to an electric bicycle most specifically to a system capable of detecting the direction of rotation of the rotor as well as its speed by the use of an optical sensor whereby to control the amplitude of the current in the motor.

The electronic supply includes a power electronics supply and a current control electronics circuit. Both systems can be inserted inside the motor housing, in the center of the stator yoke. The power electronics system is composed of an inverter with six Mosfets or multiple Mosfets which operate like six Mosfets. The structure diodes of the mosfets are used to ensure the current reversibility. At each sequence of conduction defined by the rotor position detector, two transistors are switched on to supply two motor phases. In the classical mode of operation, a modulation signal is applied on the gate of these two transistors. This method simplifies the control realization and only one current sensor can be inserted in the DC bus for the current measurement.

Another solution consists in applying the modulation signal on one transistor only at each sequence of operation: this method is the single switch modulation technique. The other transistor is switched "on" during all the duration of this sequence of conduction. This mode of operation is described in E.M.I. tests on a brushless actuator: Comparison of M. Lajoie-Mazene, J.P. Berry – European Power Electronics – Brighton (U.K.), September 1993 [2], in the case of monitoring operation only, compared to the classical mode of operation, where the modulation signal is applied on the gate of the two transistors. It is shown that the single switch modulation provides lower electromagnetic interferences (EMI) and reduces the commutation losses, the conduction losses in low voltage applications, the current ripple and the size of the input filtering capacitor. The proposed

electronic system is using the single switch modulation and it can be used for motor as well as generator operation. Consequently, the current regulation is realized without any external current sensor.

SUMMARY OF THE INVENTION

It is a feature of the present invention to provide a high performance brushless DC permanent magnet motor and a pulse width modulation electronic inverter for the motorization of electric vehicles supplied with electrical batteries. The motor structure

with coils of insulated wire being wound around the teeth. The rotor is connected to a hub of the wheel. Control circuit means is provided to control the torque of the motor and therefore its arresting force.

BRIEF DESCRIPTION OF THE DRAWING

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a brushless DC motor structure including a motor, a power electronics system and a current control system;

Fig 2 is a diagrammatic view of the twenty-two pole rotor and the twenty-four slot stator arrangement in accordance with principles of the present invention;
Fig 3 is a first coil winding diagram arrangement with one coil per slot;
Fig. 4 is a second coil winding arrangement with two coils per slot;
Fig 5 indicates the position of the three Hall sensors in the motor which are used to detect the rotor position;
Fig 6 is a simplified diagram of the electronic system (power electronics system (inverter) and control system);
Fig 7 shows the conduction sequence order of the power mosfets;
Fig 8 shows the simplified waveforms of the phase current in phase with the back electromotive force;
Fig 9 shows the diagram of the mosfet control signals during one period of the motor operation mode;
Fig 10 indicates the current flow in the case of the sequence (T1 – T2) in motor operation mode;
Fig 11 is a diagram of the mosfet control signals during one period of the generator operation mode;

As shown in Fig. 2, the proposed solution in the present invention is to use a motor 10 structure having a twenty-two poles and twenty-four slots 18 with a cylindrical outer rotor 19. Permanent magnets 20 are mounted on the rotor inner surface 21 and alternatively magnetized north and south. The high number of poles reduces the iron volume and provides acceptable iron losses when the speed is less than 1,000 rpm. A stator core (8) of ferromagnetic material is spaced inwardly of the rotor (19) and magnets (20) and defines a magnetic clearance gap (9) therebetween.

As shown in Fig's 3 and 4, a concentrated winding 22 is wound around the teeth 23. The advantages of a concentrated winding around the teeth in comparison with a classical distributed winding are described in Konecny U.S. Pat. No. 4,774,428 and the article reference E.M.I. tests on a brushless actuator: Comparison of different operation modes – J. Cros, S. Astier, J.M. Vinassa, M. Lajoie-Mazenc, J.P Berry– European Power Electronics – Brighton (UK), September 1993. [1]. The volume of copper is reduced and subsequently the Joule losses are minimized. The energy efficiency and the motor starting torque per unit volume of winding are maximized.

A first winding configuration with only one coil (7) per slot, as shown in Fig. 3, maximizes the winding coefficient (0.958) and the slot filling factor and simplifies the winding realization. An alternative winding configuration with two coils per slots is presented on Fig 4 and it can be used for the proposed motor structure (winding coefficient : 0.949). Referring now to Fig. 5, the assembling of the rotor position sensor, i.e. Hall detectors 24, near the air gap 25, is simplified by the winding configuration of Fig. 3, using one coil per slot. The Hall detectors 24 are fixed on the side of several teeth 23 which have no winding, such as teeth 23' in Fig. 3, and they are using the leakage flux of the permanent magnets to detect the rotor position. Hall sensors or detectors 24 are placed to position the phase current and the phase electromagnetic force (back emf) waveforms like in Fig's 7 & 8. The maximum value of the torque to current ratio is then obtained with this configuration.

The cogging torque ripple are greatly reduced without any slot skewing, as in the other structure combinations described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378. The least common multiple (LCM) of the motor's poles and slots describes how many peaks of cogging torque will be present over a single revolution of the motor. In this case, there are 264 torque pulses per revolution and consequently, the cogging torque amplitude is very low (less than 3% of the rated torque). The proposed motor structure also minimizes the net radial force like another structure described by Huang and al. U.S. Pat. No. 5,675,196.

Referring now to Fig. 6 there is shown the electronic supply which includes a power electronics system and a low power control electronics system. Both systems can be inserted in the cavity 26 inside the motor housing, in the center if the stator yoke 27. The power electronics system is a six switches, PWM (pulse width modulation) inverter 28. Six type N Mosfets 28 (T1, T2, T3, T'1, T'2, T'3) are used and the structure diodes of the mosfets 29 are used to ensure the current reversibility. The electronic system also includes a push-pull driver 30 for each mosfet, three boostrap supplies 31 feed the driver stages of the three transistors T'1, T'2, T'3 of the upper side of the inverter 28 and three level-shift control signals are applied to the driver stages of transistor T'1, T'2, T'3.

A current regulation circuit 32 generates a PWM signal at each transistor control signal. The voltages of the power mosfets 29' T1, T2, T3 on the lower side 28' of the inverter 28 are used to measure the motor currents. The rotor position sensors 24 define the conduction sequence order and are also used to select the voltage of the power mosfet 29 in conduction to be sensed by means of a multiplexer 33 with 3 inputs 33' and 1 output 33". The multiplexer 33 is used to generate a signal equivalent to the motor current, which can be used in the current regulation loop. The operator can select the operation mode of the system (motor or generator operation mode) and the current reference level to impose the torque of the machine.

We claim:

1. A brushless DC motor/generator (10) comprising; a cylindrical outer rotor (19) with twenty two poles (20) constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core (8) of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap (9) therebetween, said stator core having twenty-four slots (18) and defining teeth (23) between said slots (18), a three phase winding with coils (7) of insulated wire being wound around the teeth, an electronic supply (11) including a power electronics system and a current control circuit means (14) to control the torque of said motor (10) and therefore its arresting force for braking a wheel (53) of devices on which people are displaced by said DC motor motorizing said wheel, characterized in that there is one coil per slots with predetermined connection patterns: A', C, C, B', B', A, A, C', C', B, B, and A' resulting in reduced torque ripple without any slot or magnet skewing.

2. A brushless DC motor/generator (10) comprising; a cylindrical outer rotor (19) with twenty two poles (20) constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core (8) of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap (9) therebetween, said stator core having twenty-four slots (18) and defining teeth (23) between said slots (18), a three phase winding with coils (7) of insulated wire being wound around the teeth, an electronic supply (11) including a power electronics system and a current control circuit means (14) to control the torque of said motor (10) and therefore its arresting force for braking a wheel (53) of devices on which people are displaced by said DC motor motorizing said wheel, characterized in that an additional two coils (7) per slot (18) with predetermined connection patterns: C', C, C', C B, B', B, B', A', A, A', A, C, C', C, C', B', B, B', B, A, A', A, A', resulting in reduced torque ripple without any slot or magnet skewing.

3. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that a multiple combination of additions of the number of said twenty-two poles and

said twenty-four slots (18), such as forty-four said poles and forty-eight said slots, or sixty-six said poles and seventy-two said slots or ninenty-six said poles and eighty-eight said slots; and a wound winding (7) around said teeth (23) with one of either one coil per slot or two coils per slot.

4. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that there are three Hall sensors (24) are mounted near said air gap (25) at predetermined positions and fixed to or side some of said teeth (23).

5. A brushless DC motor/generator (10) as claimed in claim 4 characterized in that there is a power electronics pulse width modulation driver (30) said pulse width modulation driver (30) having a three phase inverter (28) including six power mosfets (29), said current control system (32) being coupled to said inverter (28) for generating 120 electrical degrees rectangular phase current pulses, said control system (14) using a single switch modulation technique.

6. A brushless DC motor/generator (10) as claimed in claim 5 characterized in that said single switch modulation technique is comprised of three of said mosfets 30 being connected as an upper side of said inverter (28) and remain switched "on" by a modulation signal during a motor operation mode of said motor (10), three others of said mosfets (30) being connected as a lower side of said inverter (28) and used to measure motor phase currents during all sequences of the mosfets of said upper side.

7. A brushless DC motor/generator (10) as claimed in claim 6 characterized in that said mosfets (30) of said upper side of said inverter (28) are switched "off" during a generator operation mode of said DC motor (10), and wherein a modulation signal is applied on a gate of said three mosfets on said lower side of said inverter.

8. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that said motor (10) is also used as a wheel braking device when used in a generator

mode, said rotor (19) being connected to a hub (52) of a wheel (53) powered by said motor (10) when in a motorized mode.

9. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that said control circuit means (14) comprises: a power electronics three phase inverter (28) provided with six power mosfets (30), a current control system (14) coupled to said inverter (28) for generating 120 electrical degrees rectangular phase current pulses, an electronic control system (32) for both a motor and a generator operation mode of said motor (10) and using a single switch modulation technique.

10. A brushless DC motor/generator (10) as claimed in claim 9 characterized in that voltages across said mosfets (30) on a lower side of said inverter (28) are used to generate a current measurement for the purpose of motor current control of said single switch modulation technique.

1/10

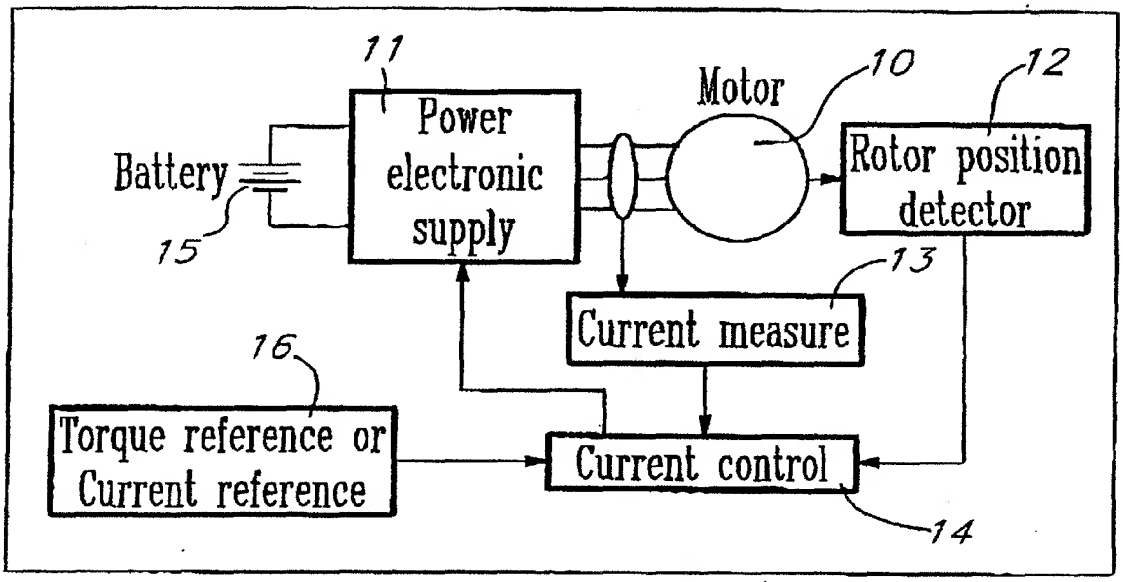

FIG_1

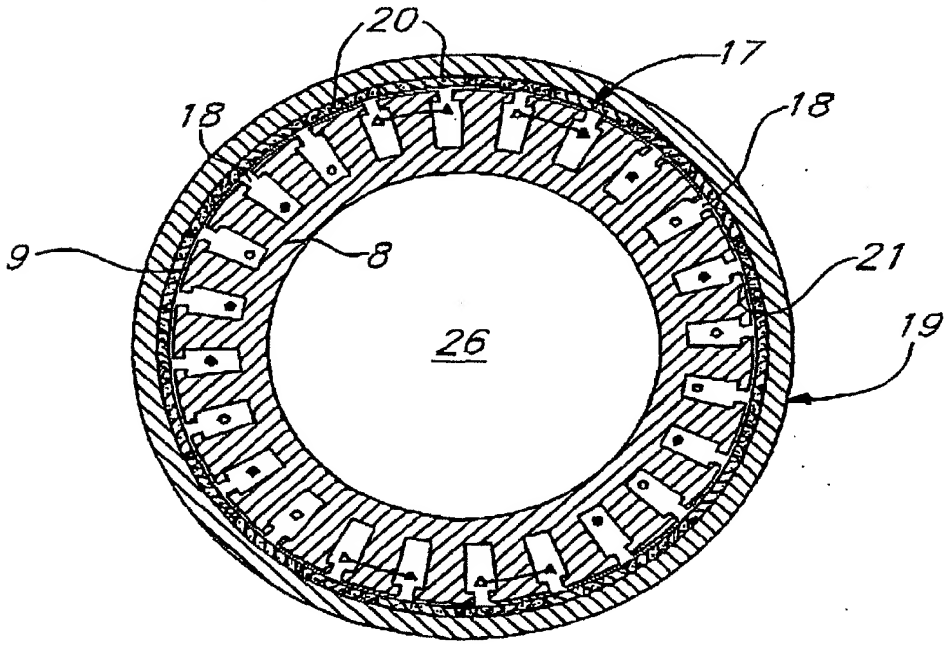

FIG_2

2/10

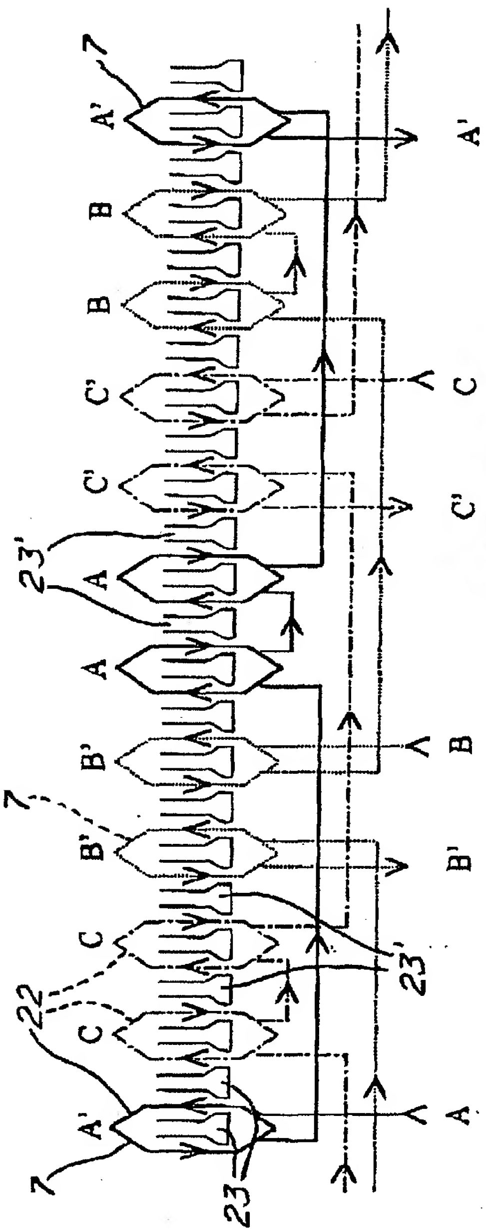

FIG. 3

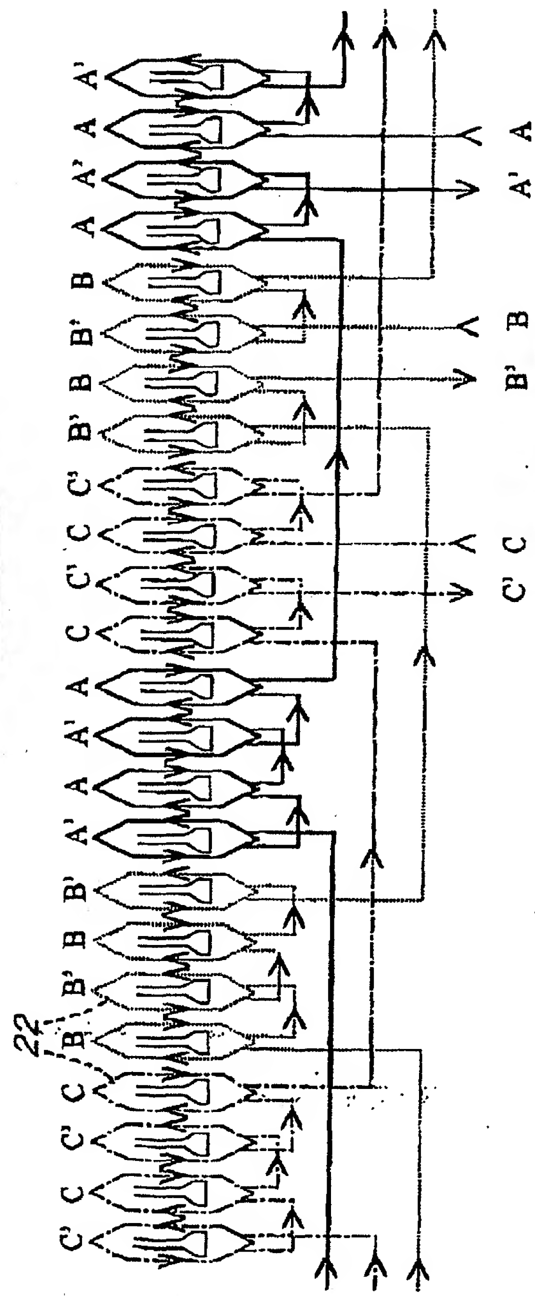

FIG. 4

INTERNATIONAL SEARCH REPORT

Interna[redacted]pplication No
PCT/CA 99/00290

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02K21/22 H02P6/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02K H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 006 745 A (NISHIO AKIRA ET AL) 9 April 1991 (1991-04-09) column 7, line 63 -column 8, line 9; claim 3; table 5 column 10, line 19 - line 35; claim 4; figure 7	2,3 5-8
X	US 5 164 622 A (KORDIK JEFFREY A) 17 November 1992 (1992-11-17) column 9, line 52 - line 53; figure 1 column 7, line 40 - line 47; figures 1,3	2-4
X	GB 2 289 991 A (CHAN CHING CHUEN) 6 December 1995 (1995-12-06) page 1, paragraph 3 - paragraph 4; figures 1A,2	1

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2000	27/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Roy, C

2

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Interr[illegible]pplication No
PCT/CA 99/00290

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 675 196 A (HUANG BEN ET AL) 7 October 1997 (1997-10-07) column 6, line 7 -column 7, line 13	1,2
Y	US 3 783 359 A (MALKIEL S) 1 January 1974 (1974-01-01) column 2, line 49 - line 55; figure 2 column 3, line 45 -column 4, line 10; figure 3	5-7,9,10
Y	PATENT ABSTRACTS OF JAPAN vol. 013, no. 184 (E-751), 28 April 1989 (1989-04-28) & JP 01 008897 A (NIPPON DENSO CO LTD), 12 January 1989 (1989-01-12) abstract	5-7,9,10
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 145 (M-1233), 10 April 1992 (1992-04-10) & JP 04 004703 A (NIPPON STEEL CORP), 9 January 1992 (1992-01-09)	11
Y	abstract	8
A	EP 0 521 709 A (TOKYO SHIBAURA ELECTRIC CO ;TOSHIBA MICRO ELECTRONICS (JP)) 7 January 1993 (1993-01-07) figures 1,2	

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter[redacted]pplication No
PCT/CA 99/00290

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5006745 A	09-04-1991	JP 1984917 C	25-10-1995
		JP 2046153 A	15-02-1990
		JP 7008123 B	30-01-1995
		JP 2142350 A	31-05-1990
US 5164622 A	17-11-1992	NONE	
GB 2289991 A	06-12-1995	NONE	
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		CA 2210064 A	29-05-1997
		EP 0804828 A	05-11-1997
		JP 10513338 T	15-12-1998
		WO 9719505 A	29-05-1997
US 3783359 A	01-01-1974	NONE	
JP 01008897 A	12-01-1989	NONE	
JP 04004703 A	09-01-1992	NONE	
EP 0521709 A	07-01-1993	JP 5015157 A	22-01-1993
		DE 69210487 D	13-06-1996
		DE 69210487 T	31-10-1996
		US 5373436 A	13-12-1994

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
14074-1PCT		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/CA 99/ 00290	01/04/1999	
Applicant		
DUBE, Jean-Yves		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3, 4

   [ ] as suggested by the applicant.

   [ ] because the applicant failed to suggest a figure.

   [X] because this figure better characterizes the invention.

   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PC[redacted]A 99/00290

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02K21/22 H02P6/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02K H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 006 745 A (NISHIO AKIRA ET AL) 9 April 1991 (1991-04-09) column 7, line 63 -column 8, line 9; claim 3; table 5 column 10, line 19 - line 35; claim 4; figure 7	2,3 5-8
X	US 5 164 622 A (KORDIK JEFFREY A) 17 November 1992 (1992-11-17) column 9, line 52 - line 53; figure 1 column 7, line 40 - line 47; figures 1,3	2-4
X	GB 2 289 991 A (CHAN CHING CHUEN) 6 December 1995 (1995-12-06) page 1, paragraph 3 - paragraph 4; figures 1A,2	1

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2000	27/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Roy, C

2

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PC[redacted]A 99/00290

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 675 196 A (HUANG BEN ET AL) 7 October 1997 (1997-10-07) column 6, line 7 -column 7, line 13	1,2
Y	US 3 783 359 A (MALKIEL S) 1 January 1974 (1974-01-01) column 2, line 49 - line 55; figure 2 column 3, line 45 -column 4, line 10; figure 3	5-7,9,10
Y	PATENT ABSTRACTS OF JAPAN vol. 013, no. 184 (E-751), 28 April 1989 (1989-04-28) & JP 01 008897 A (NIPPON DENSO CO LTD), 12 January 1989 (1989-01-12) abstract	5-7,9,10
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 145 (M-1233), 10 April 1992 (1992-04-10) & JP 04 004703 A (NIPPON STEEL CORP), 9 January 1992 (1992-01-09)	11
Y	abstract	8
A	EP 0 521 709 A (TOKYO SHIBAURA ELECTRIC CO ;TOSHIBA MICRO ELECTRONICS (JP)) 7 January 1993 (1993-01-07) figures 1,2	

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PC[redacted]A 99/00290

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5006745 A	09-04-1991	JP 1984917 C	25-10-1995
		JP 2046153 A	15-02-1990
		JP 7008123 B	30-01-1995
		JP 2142350 A	31-05-1990
US 5164622 A	17-11-1992	NONE	
GB 2289991 A	06-12-1995	NONE	
US 5675196 A	07-10-1997	AU 7463196 A	11-06-1997
		CA 2210064 A	29-05-1997
		EP 0804828 A	05-11-1997
		JP 10513338 T	15-12-1998
		WO 9719505 A	29-05-1997
US 3783359 A	01-01-1974	NONE	
JP 01008897 A	12-01-1989	NONE	
JP 04004703 A	09-01-1992	NONE	
EP 0521709 A	07-01-1993	JP 5015157 A	22-01-1993
		DE 69210487 D	13-06-1996
		DE 69210487 T	31-10-1996
		US 5373436 A	13-12-1994

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

14

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
14074-1PCT		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/CA 99/00290	01/04/1999	
International Patent Classification (IPC) or national classification and IPC		
H02K21/22		
Applicant		
DUBE, Jean-Yves		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consists of a total of 10 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☒ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
26/10/2000	10.07.01
Name and mailing address of the IPEA/	Authorized officer
European Patent Office D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	E. Le Guay

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/CA99/00290

I. Basis of the report

1. This report has been drawn up on the basis of *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.)*

☐	the international application as originally filed			
☒	the description, pages	1-3, 5, 6, 8, 11, 12	, as originally filed	
	pages		, filed with the demand	
	pages	4, 4a, 7, 9, 10	, filed with the letter of	16.05.01
☒	the claims, Nos.		, as originally filed	
	Nos.		, as amended under Article 19	
	Nos.		, filed with the demand	
	Nos.	1-10	, filed with the letter of	16.05.01
☒	the drawings, sheets / fig.	3/10-10/10	, as originally filed	
	sheets / fig.		, filed with the demand	
	sheets / fig.	1/10-2/10	, filed with the letter of	16.05.01

2. The amendments have resulted in the cancellation of:

☐ the description, pages:

☐ the claims, Nos.

☐ the drawings, sheets / fig.

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2 (c)).

4. Additional observations, if necessary:

IV. Lack of unity of invention

1. In response to the invitation (Form PCT/IPEA/405) to restrict or pay additional fees the applicant has:

- ☐ restricted the claims.
- ☐ paid additional fees.
- ☐ paid additional fees under protest.
- ☒ neither restricted nor paid additional fees.

2. ☐ This Authority found that the requirement of unity of invention is not complied with and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

- ☐ complied with.
- ☒ not complied with for the following reasons:

1. The separate inventions/groups of invention are:

   a. a brushless DC motor wound with one coil per slot (Claim 1)
   b. a brushless DC motor wound with two coils per slot (Claim 2)

2. They are not so linked as to form a single general inventive concept (Rule 13.1 PCT) for the following reasons:

   The common subject-matter between the two groups of claims is known and acknowledged to be known. Thus, said common subject-matter is limited to the preamble of Claims 1 and 2. On the other hand, there is no common relevant feature between the characterizing part of Claim 1 and the one of Claim 2.

   Therefore, there is a lack of unity of invention between Claim 1 and Claim 2.

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

- ☐ all parts.
- ☒ the parts relating to claims Nos. 1, 3-10

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty	Claims	1, 3-10	YES
	Claims	None	NO
Inventive Step	Claims	1, 3-10	YES
	Claims	None	NO
Industrial Applicability	Claims	1, 3-10	YES
	Claims	None	NO

2. Citations and Explanations

1. Concerning Claim 1:

a. Claim 1 relates to a brushless DC motor/generator having a 22-pole rotor, a 24-slot stator and an electronic supply;

b. nearest prior art is document GB-A-2 289 991 which discloses such a machine;

c. the claimed machine additionally discloses a specific predetermined connection pattern;

d. the purpose of this specific pattern is to reduce the torque ripple of the machine;

e. this additional feature is new and inventive with respect to the available prior art as none of the cited documents discloses or suggests such a pattern;

f. therefore, Claim 1 complies with the requirements of Article 33(2) and (3) PCT.

2. Concerning Claims 3 to 10:

These depending claims disclose particular embodiments of the invention. Therefore, they have to be considered as novel and inventive in terms of Article 33(2) and (3) PCT.

3. The industrial applicability of the motor according to Claims 1 and 3 to 10 is obvious.

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

1. Claim 3 is not consistent with Claims 1 and 2 from which it depends.

   Thus Claims 1 and 2 disclose a motor with twenty-two poles and twenty-four slots. Claim 3, on the contrary, discloses different numbers of poles and slots. Like (44, 48), (66, 72) and (96,88).

2. Claim 5 lacks clarity in terms of Article 6 PCT.

   This claim discloses a modulation driver (30) while reference number 30 has been used for push-pulls in the description and the figures (see page 9 and figure 6).

   Moreover, Claim 5 discloses "said current control (32)" although such a current control has not yet been evoked.

3. The same applies for Claim 9 which discloses "power mosfets (30)".

Reference is made to British Patent GB 2 289 991 which discloses a winding sequence for a motor having twelve slots and ten poles. It is described in that Patent the use of a specific rotor structure and a specific winding sequence wherein one winding per slot is provided to obtain independent magnetic flux flow for each phase.

Japanese Patent A-400 4703 relates to an electric bicycle most specifically to a system capable of detecting the direction of rotation of the rotor as well as its speed by the use of an optical sensor whereby to control the amplitude of the current in the motor.

The electronic supply includes a power electronics supply and a current control electronics circuit. Both systems can be inserted inside the motor housing, in the center of the stator yoke. The power electronics system is composed of an inverter with six Mosfets or multiple Mosfets which operate like six Mosfets. The structure diodes of the mosfets are used to ensure the current reversibility. At each sequence of conduction defined by the rotor position detector, two transistors are switched on to supply two motor phases. In the classical mode of operation, a modulation signal is applied on the gate of these two transistors. This method simplifies the control realization and only one current sensor can be inserted in the DC bus for the current measurement.

Another solution consists in applying the modulation signal on one transistor only at each sequence of operation: this method is the single switch modulation technique. The other transistor is switched "on" during all the duration of this sequence of conduction. This mode of operation is described in E.M.I. tests on a brushless actuator: Comparison of M. Lajoie-Mazene, J.P. Berry – European Power Electronics – Brighton (U.K.), September 1993 [2], in the case of monitoring operation only, compared to the classical mode of operation where the modulation signal is applied on the gate of the two transistors. It is shown that the single switch modulation provides lower electromagnetic interferences (EMI) and reduces the commutation losses, the conduction losses in low voltage applications, the current ripple and the size of the input filtering capacitor. The proposed

electronic system is using the single switch modulation and it can be used for motor as well as generator operation. Consequently, the current regulation is realized without any external current sensor.

SUMMARY OF THE INVENTION

It is a feature of the present invention to provide a high performance brushless DC permanent magnet motor and a pulse width modulation electronic inverter for the motorization of electric vehicles supplied with electrical batteries. The motor structure

with coils of insulated wire being wound around the teeth. The rotor is connected to a hub of the wheel. Control circuit means is provided to control the torque of the motor and therefore its arresting force.

BRIEF DESCRIPTION OF THE DRAWING

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a brushless DC motor structure including a motor, a power electronics system and a current control system;

Fig 2 is a diagrammatic view of the twenty-two pole rotor and the twenty-four slot stator arrangement in accordance with principles of the present invention;
Fig 3 is a first coil winding diagram arrangement with one coil per slot;
Fig. 4 is a second coil winding arrangement with two coils per slot;
Fig 5 indicates the position of the three Hall sensors in the motor which are used to detect the rotor position;
Fig 6 is a simplified diagram of the electronic system (power electronics system (inverter) and control system);
Fig 7 shows the conduction sequence order of the power mosfets;
Fig 8 shows the simplified waveforms of the phase current in phase with the back electromotive force;
Fig 9 shows the diagram of the mosfet control signals during one period of the motor operation mode;
Fig 10 indicates the current flow in the case of the sequence (T1 – T2) in motor operation mode;
Fig 11 is a diagram of the mosfet control signals during one period of the generator operation mode;

As shown in Fig. 2, the proposed solution in the present invention is to use a motor 10 structure having a twenty-two poles and twenty-four slots 18 with a cylindrical outer rotor 19. Permanent magnets 20 are mounted on the rotor inner surface 21 and alternatively magnetized north and south. The high number of poles reduces the iron volume and provides acceptable iron losses when the speed is less than 1,000 rpm. A stator core (8) of ferromagnetic material is spaced inwardly of the rotor (19) and magnets (20) and defines a magnetic clearance gap (9) therebetween.

As shown in Fig's 3 and 4, a concentrated winding 22 is wound around the teeth 23. The advantages of a concentrated winding around the teeth in comparison with a classical distributed winding are described in Konecny U.S. Pat. No. 4,774,428 and the article reference E.M.I. tests on a brushless actuator: Comparison of different operation modes – J. Cros, S. Astier, J.M. Vinassa, M. Lajoie-Mazenc, J.P Berry– European Power Electronics – Brighton (UK), September 1993. [1]. The volume of copper is reduced and subsequently the Joule losses are minimized. The energy efficiency and the motor starting torque per unit volume of winding are maximized.

A first winding configuration with only one coil (7) per slot, as shown in Fig. 3, maximizes the winding coefficient (0.958) and the slot filling factor and simplifies the winding realization. An alternative winding configuration with two coils per slots is presented on Fig 4 and it can be used for the proposed motor structure (winding coefficient : 0.949). Referring now to Fig. 5, the assembling of the rotor position sensor, i.e. Hall detectors 24, near the air gap 25, is simplified by the winding configuration of Fig. 3, using one coil per slot. The Hall detectors 24 are fixed on the side of several teeth 23 which have no winding, such as teeth 23' in Fig. 3, and they are using the leakage flux of the permanent magnets to detect the rotor position. Hall sensors or detectors 24 are placed to position the phase current and the phase electromagnetic force (back emf) waveforms like in Fig's 7 & 8. The maximum value of the torque to current ratio is then obtained with this configuration.

The cogging torque ripple are greatly reduced without any slot skewing, as in the other structure combinations described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378. The least common multiple (LCM) of the motor's poles and slots describes how many peaks of cogging torque will be present over a single revolution of the motor. In this case, there are 264 torque pulses per revolution and consequently, the cogging torque amplitude is very low (less than 3% of the rated torque). The proposed motor structure also minimizes the net radial force like another structure described by Huang and al. U.S. Pat. No. 5,675,196.

Referring now to Fig. 6 there is shown the electronic supply which includes a power electronics system and a low power control electronics system. Both systems can be inserted in the cavity 26 inside the motor housing, in the center if the stator yoke 27. The power electronics system is a six switches, PWM (pulse width modulation) inverter 28. Six type N Mosfets 28 (T1, T2, T3, T'1, T'2, T'3) are used and the structure diodes of the mosfets 29 are used to ensure the current reversibility. The electronic system also includes a push-pull driver 30 for each mosfet, three boostrap supplies 31 feed the driver stages of the three transistors T'1, T'2, T'3 of the upper side of the inverter 28 and three level-shift control signals are applied to the driver stages of transistor T'1, T'2, T'3.

A current regulation circuit 32 generates a PWM signal at each transistor control signal. The voltages of the power mosfets 29' T1, T2, T3 on the lower side 28' of the inverter 28 are used to measure the motor currents. The rotor position sensors 24 define the conduction sequence order and are also used to select the voltage of the power mosfet 29 in conduction to be sensed by means of a multiplexer 33 with 3 inputs 33' and 1 output 33". The multiplexer 33 is used to generate a signal equivalent to the motor current, which can be used in the current regulation loop. The operator can select the operation mode of the system (motor or generator operation mode) and the current reference level to impose the torque of the machine.

We claim:

1. A brushless DC motor/generator (10) comprising; a cylindrical outer rotor (19) with twenty two poles (20) constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core (8) of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap (9) therebetween, said stator core having twenty-four slots (18) and defining teeth (23) between said slots (18), a three phase winding with coils (7) of insulated wire being wound around the teeth, an electronic supply (11) including a power electronics system and a current control circuit means (14) to control the torque of said motor (10) and therefore its arresting force for braking a wheel (53) of devices on which people are displaced by said DC motor motorizing said wheel, characterized in that there is one coil per slots with predetermined connection patterns: A', C, C, B', B', A, A, C', C', B, B, and A' resulting in reduced torque ripple without any slot or magnet skewing.

2. A brushless DC motor/generator (10) comprising; a cylindrical outer rotor (19) with twenty two poles (20) constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core (8) of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap (9) therebetween, said stator core having twenty-four slots (18) and defining teeth (23) between said slots (18), a three phase winding with coils (7) of insulated wire being wound around the teeth, an electronic supply (11) including a power electronics system and a current control circuit means (14) to control the torque of said motor (10) and therefore its arresting force for braking a wheel (53) of devices on which people are displaced by said DC motor motorizing said wheel, characterized in that an additional two coils (7) per slot (18) with predetermined connection patterns: C', C, C', C B, B', B, B', A', A, A', A, C, C', C, C', B', B, B', B, A, A', A, A', resulting in reduced torque ripple without any slot or magnet skewing.

3. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that a multiple combination of additions of the number of said twenty-two poles and

said twenty-four slots (18), such as forty-four said poles and forty-eight said slots, or sixty-six said poles and seventy-two said slots or ninenty-six said poles and eighty-eight said slots; and a wound winding (7) around said teeth (23) with one of either one coil per slot or two coils per slot.

4. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that there are three Hall sensors (24) are mounted near said air gap (25) at predetermined positions and fixed to or side some of said teeth (23).

5. A brushless DC motor/generator (10) as claimed in claim 4 characterized in that there is a power electronics pulse width modulation driver (30) said pulse width modulation driver (30) having a three phase inverter (28) including six power mosfets (29), said current control system (32) being coupled to said inverter (28) for generating 120 electrical degrees rectangular phase current pulses, said control system (14) using a single switch modulation technique.

6. A brushless DC motor/generator (10) as claimed in claim 5 characterized in that said single switch modulation technique is comprised of three of said mosfets 30 being connected as an upper side of said inverter (28) and remain switched "on" by a modulation signal during a motor operation mode of said motor (10), three others of said mosfets (30) being connected as a lower side of said inverter (28) and used to measure motor phase currents during all sequences of the mosfets of said upper side.

7. A brushless DC motor/generator (10) as claimed in claim 6 characterized in that said mosfets (30) of said upper side of said inverter (28) are switched "off" during a generator operation mode of said DC motor (10), and wherein a modulation signal is applied on a gate of said three mosfets on said lower side of said inverter.

8. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that said motor (10) is also used as a wheel braking device when used in a generator

mode, said rotor (19) being connected to a hub (52) of a wheel (53) powered by said motor (10) when in a motorized mode.

9. A brushless DC motor/generator (10) as claimed in claim 1 or 2 characterized in that said control circuit means (14) comprises: a power electronics three phase inverter (28) provided with six power mosfets (30), a current control system (14) coupled to said inverter (28) for generating 120 electrical degrees rectangular phase current pulses, an electronic control system (32) for both a motor and a generator operation mode of said motor (10) and using a single switch modulation technique.

10. A brushless DC motor/generator (10) as claimed in claim 9 characterized in that voltages across said mosfets (30) on a lower side of said inverter (28) are used to generate a current measurement for the purpose of motor current control of said single switch modulation technique.

1/10

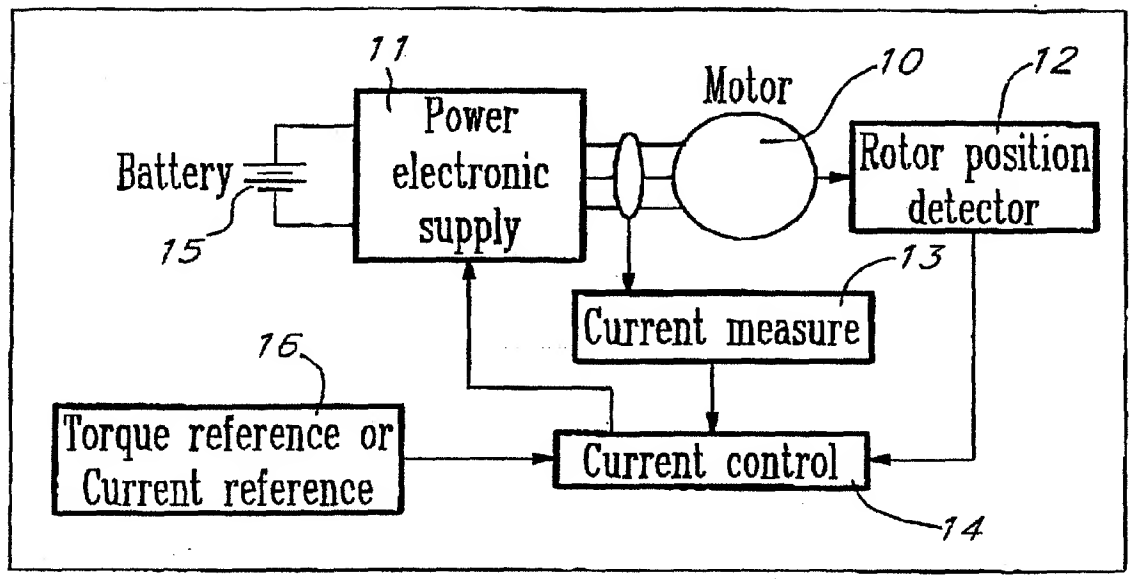

Fig. 1

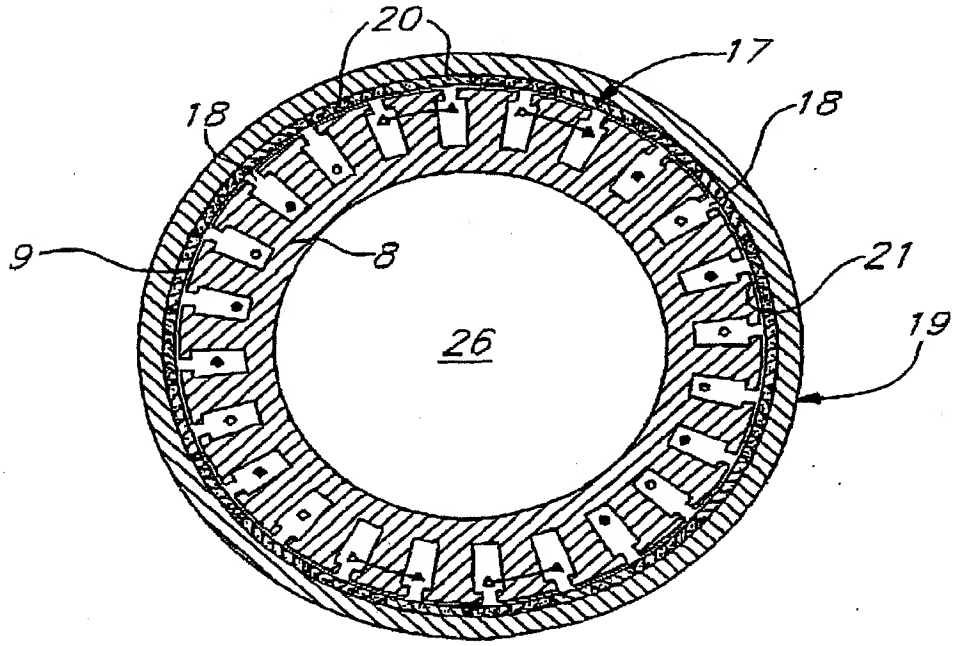

Fig. 2

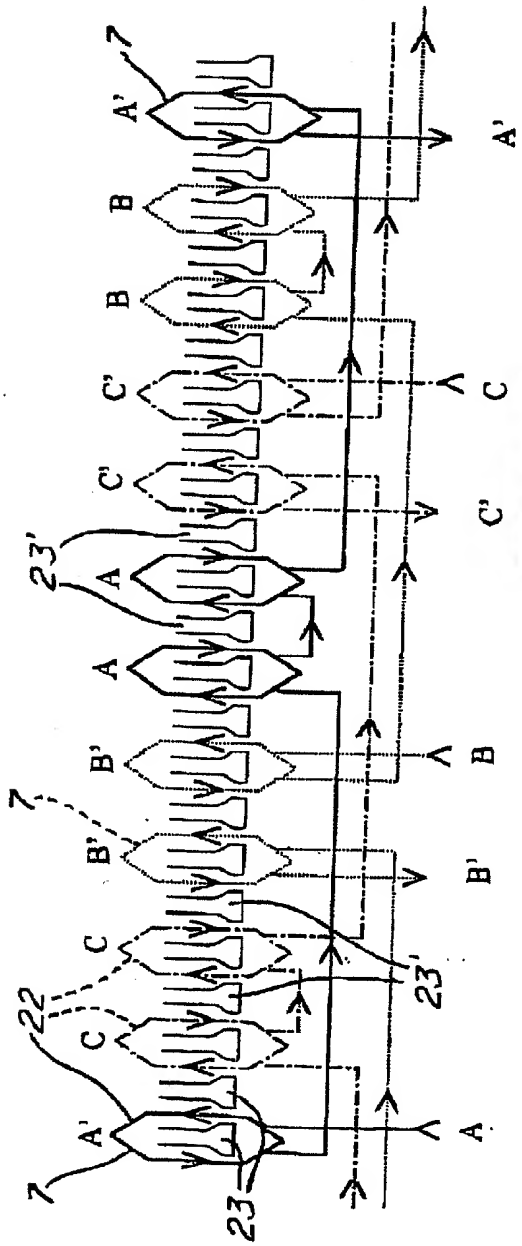

Fig. 3

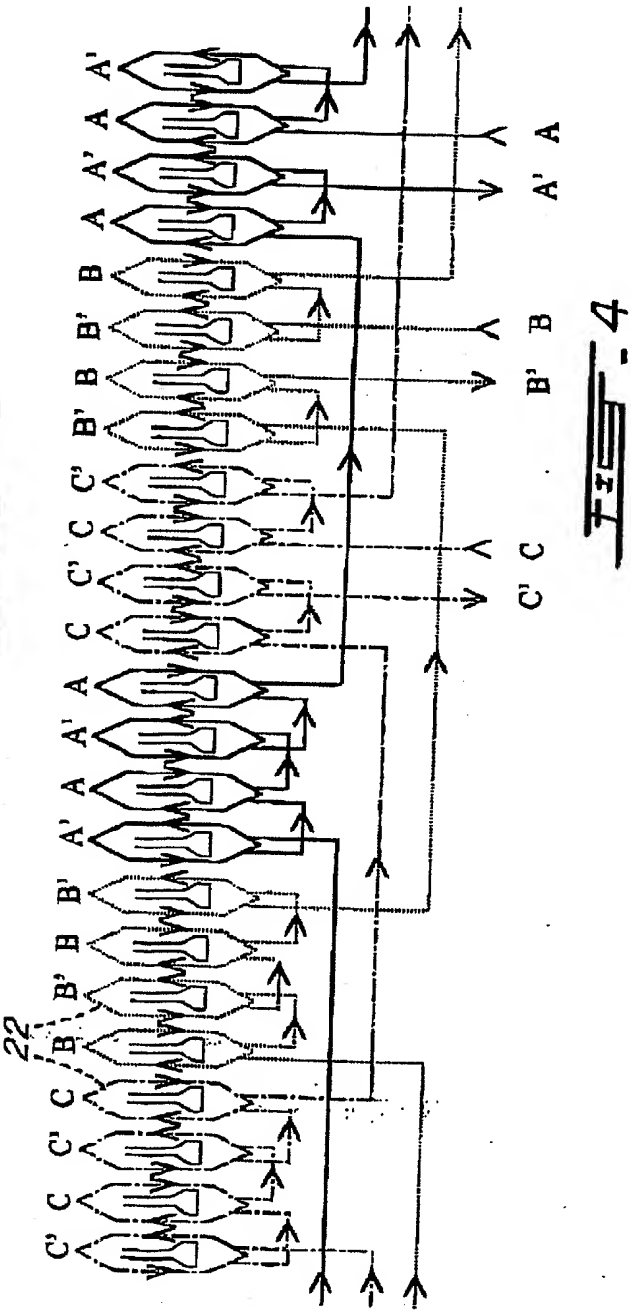

Fig. 4

PCT ORLD INTELLECTUAL PROPERTY ORGANIZA
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : H02K 21/22, H02P 6/24

A1

(11) International Publication Number: **WO 00/60724**

(43) International Publication Date: 12 October 2000 (12.10.00)

(21) International Application Number: PCT/CA99/00290

(22) International Filing Date: 1 April 1999 (01.04.99)

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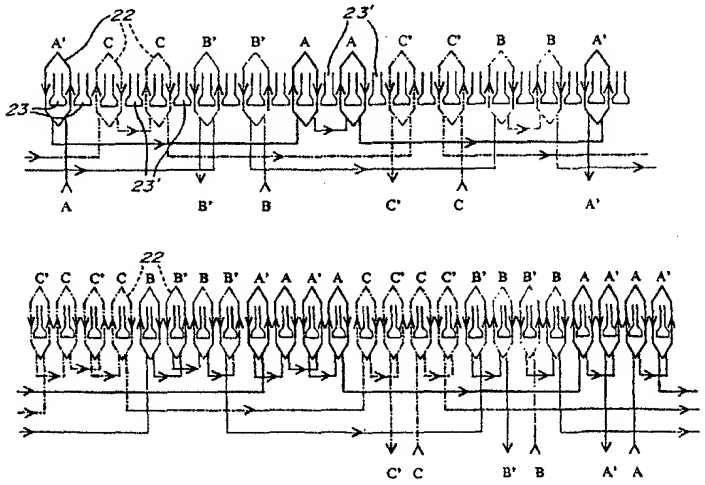
(54) Title: HIGH PERFORMANCE BRUSHLESS MOTOR AND DRIVE FOR AN ELECTRICAL VEHICLE MOTORIZATION



(57) Abstract

The system includes a permanent magnet three-phase motor and an electronic current controlled inverter by pulse width modulation. The motor has twenty-two poles and twenty-four slots, three phases and a cylindrical outer rotor. This structure minimizes torque ripple and maximizes energy efficiently. All coil windings are wound around the stator teeth. Several winding configurations are proposed and a special one with only one coil per slot. The motor phases are supplied by alternating rectangular current waveforms. A specific inverter control system is described to maximize efficiency and reduce current ripple and electromagnetic interference under motorizing or generating operations. The current control is realized by using the mosfets voltage for the current measurement.

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HIGH PERFORMANCE BRUSHLESS MOTOR AND DRIVE FOR AN ELECTRICAL VEHICLE MOTORIZATION

BACKGROUND OF THE INVENTION

The present invention relates to a low cost electric system composed of a new DC brushless permanent magnet motor and its electronic drive which provides high efficiency operation and low torque ripple for the motorization of electric vehicles like, bicycles, rolling chairs, scooters, tricycles, golf cars, trolleys and small utility vehicles.

The motor and its electronic system are supplied by one or several batteries. The vehicle wheel drive can be direct to maximize efficiency or equipped with a speed reducer to minimize the motor size. The proposed solution uses a permanent magnet three-phase motor which can reach four times the nominal torque. This motor structure includes an outer rotor which can be fitted into a vehicle wheel. It can be used as motor or generator with energy recuperation in the battery during braking periods or to create electricity to recharge battery, or power other devices by changing the motor. This motor structure is supplied by a PWM (Pulse Width Modulation) current controlled inverter. The operator can impose the machine torque level in motor or generator operation by setting a current reference. The shape of the alternative phase current waveform is rectangular with a width of 120 electrical degrees. This kind of motor supply is the simplest to realize and it reduces the cost of the control system and the number of sensors.

The brushless motor includes a cylindrical outer rotor wherein permanent magnets are mounted on the surface and an internal stator with coils of insulated wire wound around the teeth. There are twenty two magnet poles on the rotor alternatively magnetized north and south and twenty-four slots on the stator. This combination of slots and poles for a three-phase motor structure allows the realization of a special concentrated winding around the teeth with only one coil per slot. In this case, there are only twelve coils to realize. The winding coefficient and the copper filling factor are higher than in the other known solutions described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378 which are using winding with two coils per slot.

This kind of winding with one coil per slot simplifies the assembling of the rotor position sensors (i.e. hall detectors) near the air gap. The hall detector are fixed on the side of several teeth which have no winding and they are using the leakage flux of the permanent magnets to detect the rotor position.

The proposed structure maximizes the energy efficiency and the motor starting torque per unit volume of winding. The advantages of a concentrated winding around the teeth in comparison with a classical distributed winding are described in Konecny U.S. Pat. No. 4,774,428 and Permanent magnet Brushless DC motor with soft metal powder for automotive application – J. Cros, P. Viarouge IEEE Industry applications Society – St-Louis , October 1998. [1]. The volume of copper is reduced and subsequently the Joule losses are minimized.

The amount of vibrations and the cogging torque ripple are reduced drastically like in the other structure combinations described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378. The least common multiple (LCM) of the motor's poles and slots describes how many peaks of cogging torque will be present over a single revolution of the motor. In this case, there are 264 torque pulses per revolution and consequently, the cogging torque amplitude is very low (less than 3% of the rated torque).

The proposed motor structure also minimizes the net radial force like another structure described by Huang and al. U.S. Pat. No. 5,675,196.

The electronic supply includes a power electronics system and a control electronics system. Both systems can be inserted inside the motor housing, in the center of the stator yoke. The power electronics system is composed of an inverter with six Mosfets or multiple Mosfets which operate like six Mosfets. The structure diodes of the mosfets are used to ensure the current reversibility. At each sequence of conduction defined by the rotor position detector, two transistors are switched on to supply two motor phases. In the classical mode of operation, a modulation signal is applied on the gate of these two

system. Both systems can be inserted inside the motor housing, in the center of the stator yoke. The power electronics system is composed of an inverter with six Mosfets or multiple Mosfets which operate like six Mosfets. The structure diodes of the mosfets are used to ensure the current reversibility. At each sequence of conduction defined by the rotor position detector, two transistors are switched on to supply two motor phases. In the classical mode of operation, a modulation signal is applied on the gate of these two transistors. This method simplifies the control realization and only one current sensor can be inserted in the DC bus for the current measurement.

Another solution consists in applying the modulation signal on one transistor only at each sequence of operation: this method is the single switch modulation technique. The other transistor is switched "on" during all the duration of this sequence of conduction. This mode of operation is described in E.M.I. tests on a brushless actuator: Comparison of M. Lajoie-Mazene, J.P. Berry – European Power Electronics – Brighton (U.K.), September 1993 [2], in the case of motoring operation only, compared to the classical mode of operation where the modulation signal is applied on the gate of the two transistors. It is shown that the single switch modulation provides lower electromagnetic interferences (EMI) and reduces the commutation losses, the conduction losses in low voltage applications, the current ripple and the size of the input filtering capacitor. The proposed electronic system is using the single switch modulation and it can be used for motor as well as generator operation. Consequently, the current regulation is realized without any external current sensor.

SUMMARY OF THE INVENTION

It is a feature of the present invention to provide a high performance brushless DC permanent magnet motor and a pulse width modulation electronic inverter for the motorization of electric vehicles supplied with electrical batteries. The motor structure includes an outer rotor which can be fitted to a vehicle wheel. It can be used as a motor or as a generator with recuperation of kinetic energy in the batteries during braking periods.

Another feature of the invention is to provide a special design and the design of its three-phase winding maximize the energy efficiency and the motor starting torque per unit volume of winding. A concentrated winding is wound around the teeth with only one coil per slot. This solution simplifies the winding realization and maximizes the winding coefficient and the copper filling factor.

Another feature of the invention is that the assembling of the rotor position sensor (i.e. hall detectors) near the air gap is simplified by the winding configuration. The hall detector are fixed on the side of several teeth which have no winding and they are using the leakage flux of the permanent magnets to detect the rotor position. The amount of vibrations, the cogging torque ripple and the radial force are greatly reduced.

Another feature of the invention is to provide specific inverter control system which reduces the commutation losses, the diode conduction losses in low voltage applications, the current ripple, the size of the input filtering capacitor and electromagnetic interference. A specific single switch modulation technique is used: The modulation signal is applied only on one transistor at each sequence of operation defined by the rotor position detector. The other transistor is switched on during all the duration of this sequence of conduction. This single switch modulation method maximizes the efficiency of the electronic supply and the current regulation is realized without any external current sensor.

According to the above features, from a broad aspect, the present invention provides a brushless DC motor for electrical vehicle motorization. The motor comprises a cylindrical rotor with 22 poles constructed with segments of permanent magnet material alternatively magnetized north and south. A stator core of ferromagnetic material is spaced inwardly of the rotor and defines a magnetic clearance gap therebetween. The stator core has twenty four slots and define teeth between the slots. A three-phase winding with coils of insulated wire is wound around the teeth. There is provided one coil per slot with predetermined connection patterns A', C, C, B', B', A, A, C', C', B, B, and A' resulting in reduced torque ripple without any slot or magnet skewing.

According to a still further broad aspect of the present invention there is provided a brushless DC motor as above described but wherein there is further provided two coils per slot having predetermined connection patterns C', C, C', C, B, B', B, B', A', A, A', A, C, C', C, C', B', B, B', B, A, A', A, A'.

According to a still further broad aspect of the present invention there is provided a brushless DC motor electronic pulse with modulation driver and control system. It includes a power electronic three phase inverter having six power of mosfets. A current control system is coupled to the inverter for generating a 120 electrical degrees rectangular phase current pulses. An electronic control system is provided for both motor and a generator operation mode of the motor and uses a single switch modulation technique.

According to a still further broad aspect of the present invention there is provided a brushless DC motor for breaking a wheel of devices on which people are displaced by self-motorization or electric motor motorization. The motor comprises a cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap, therebetween said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth. The rotor is connected to a hub of the wheel. Control circuit means is provided to control the torque of the motor and therefore its arresting force.

BRIEF DESCRIPTION OF THE DRAWING

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a brushless DC motor structure including a motor, a power electronics system and a current control system;

Fig.2 is a diagrammatic view of the twenty-two pole rotor and the twenty-four slot stator arrangement in accordance with principles of the present invention;

Fig 3 is a first coil winding diagram arrangement with one coil per slot;

Fig 4 is a second coil winding arrangement with two coils per slot;

Fig 5 indicates the position of the three Hall sensors in the motor which are used to detect the rotor position;

Fig 6 is a simplified diagram of the electronic system (power electronics system (inverter) and control system);

Fig 7 shows the conduction sequence order of the power mosfets;

Fig 8 shows the simplified waveforms of the phase current and phase emf of the;

Fig 9 shows the diagram of the mosfet control signals during one period of the motor operation mode;

Fig 10 indicates the current flow in the case of the sequence (T1 – T2) in motor operation mode;

Fig 11 is a diagram of the mosfet control signals during one period of the generator operation mode;

Fig 12 indicates the current flow in the case of the sequence (T1 – T2) in generator operation mode;

Figure 13 shows a schematic view of the current control;

Figure 14 is a schematic diagram of the transformation of the signals of the rotor position sensors and the generation of the mosfet gate control signals in motor operation mode;

Figure 15 is a schematic diagram of the electronic system for the generation, the mosfet gate control signals, and the measurement of the phase current in the motor and generator operation mode with the single switch modulation technique, and

Figure 16 is a simplified fragmented side view showing the motor of the present invention coupled to a wheel of a bicycle through its rotor.

DETAILED DESCRIPTION OF THE INVENTION

In electrical vehicle applications, it is necessary to produce high starting torque and to ensure variable speed in both motor and generator modes of operation. The use of a brushless DC motor is particularly well adapted to this kind of applications. To reduce the cost of the electronic system and the number of sensors, it is better to supply the motor winding phases with a rectangular waveform current. The motor torque is

controlled by a simple current regulation and the phase voltage is chopped with a pulse width modulation technique (PWM). The schematic diagram of this kind of brushless DC motor is presented on Fig.1. It includes a permanent magnet motor 10, a power electronic supply 11, a rotor position detector 12, a current measurement system 13 and a current regulation system which is comprised of a current control circuit 14 fed by the current measuring circuit 13 and a torque reference or current reference circuit 16. The current control circuit 14 is connected to the power electric supply circuit 11 to control the torque of the motor 10. The system can be used for motor or generator operation with energy recuperation on the battery 15 during braking periods.

As shown in Fig. 2, the proposed solution in the present invention is to use a motor 10 structure having a twenty-two poles and twenty-four slots 18 with a cylindrical outer rotor 19. Permanent magnets 20 are mounted on the rotor inner surface 21 and altenatively magnetized north and south. The high number of poles reduces the iron volume and provides acceptable iron losses when the speed is less than 1,000 rpm.

As shown in Fig's 3 and 4, a concentrated winding 22 is wound around the teeth 23. The advantages of a concentrated winding around the teeth in comparison with a classical distributed winding are described in Konecny U.S. Pat. No. 4,774,428 and the article reference E.M.I tests on a brushless actuator: Comparison of different operation modes- J. Cros, S. Astier, J.M. Vinassa, M. Lajoie-Mazenc, J.P. Berry– European Power Electronics – Brighton (UK), September 1993. [1]. The volume of copper is reduced and subsequently the Joule losses are minimized. The energy efficiency and the motor starting torque per unit volume of winding are maximized.

A first winding configuration with only one coil per slot, as shown in Fig. 3, maximizes the winding coefficient (0.958) and the slot filling factor and simplifies the winding realization. An alternative winding configuration with two coils per slots is presented on Fig 4 and it can be used for the proposed motor structure (winding coefficient : 0.949). Referring now to Fig. 5, the assembling of the rotor position sensor, i.e. Hall detectors 24, near the air gap 25, is simplified by the winding configuration of Fig. 3, using one coil per slot . The Hall detectors 24 are fixed on the side of several teeth 23 which have no

winding, such as teeth 23' in Fig. 3, and they are using the leakage flux of the permanent magnets to detect the rotor position. Hall sensors or detectors 24 are placed to position the phase current and the phase electromagnetic force (back emf) waveforms like in Fig's 7 & 8. The maximum value of the torque to current ratio is then obtained with this configuration.

The cogging torque ripple are greatly reduced without any slot skewing, as in the other structure combinations described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378. The least common multiple (LCM) of the motor's poles and slots describes how many peaks of cogging torque will be present over a single revolution of the motor. In this case, there are 264 torque pulses per revolution and consequently, the cogging torque amplitude is very low (less than 3% of the rated torque). The proposed motor structure also minimizes the net radial force like another structure described by Huang and al. U.S. Pat. No. 5,675,196.

Referring now to Fig. 6 there is shown the electronic supply which includes a power electronics system and a low power control electronics system. Both systems can be inserted in the cavity 26 inside the motor housing, in the center of the stator yoke 27. The power electronics system is a six switches, PWM (pulse width modulation) inverter 26. Six type N Mosfets 28 (T1, T2, T3, T'1, T'2, T'3) are used and the structure diodes of the mosfets 29 are used to ensure the current reversibility. The electronic system also includes a push-pull driver 30 for each mosfet, three boostrap supplies 31 feed the driver stages of the three transistors T'1, T'2, T'3 of the upper side of the inverter 28 and three level–shift control signals are applied to the driver stages of transistor T'1, T'2, T'3.

A current regulation circuit 32 generates a PWM signal at each transistor control signal. The voltages of the power mosfets 29' T1, T2, T3 on the lower side 28' of the inverter 28 are used to measure the motor currents. The rotor position sensors 24 define the conduction sequence order and are also used to select the voltage of the power mosfet 29 in conduction to be sensed by means of a multiplexer 33 with 3 inputs 33' and 1 output 33". The multiplexer 33 is used to generate a signal equivalent to the motor current,

which can be used in the current regulation loop. The operator can select the operation mode of the system (motor or generator operation mode) and the current reference level to impose the torque of the machine.

Fig 7 presents the chronogram 37 of the conduction sequences of the power mosfets 29. At each time, there are only two Mosfets switched on. There are six sequences of operation in an electric period . During each sequence two phases of the machine are supplied. There are six current commutations when the rotor rotates with an angle of 32.7 degrees. The commutation process is controlled by the rotor position detectors 24 (i.e. Hall sensors).

Fig 8 shows the rectangular waveform 38 of the phase current which is in phase with the waveform 39 of the back electromotive force (back emf) of the same phase.

Referring now to Fig's 9 to 12., there is shown a single switch modulation technique used for both motor and generator operation. The modulation signal is only applied on the gate of the transistors of the inverter upper side (T'1, T'2, T'3) in the case of motor operation mode (see Fig 9 & 10). The transistors T1, T2, T3 remain switched "on" during all the duration of the conduction sequence. In comparison to the classical modulation technique where the modulation signal is applied to switches of both lower and upper sides. This specific single switch modulation technique provides lower commutation losses and lower conduction losses in the case of low voltage applications (the voltage drop of a power mosfet is lower than the voltage drop of a diode) see the E.M.I. tests article referred herein. The efficiency of the inverter 28 is higher. This single switch modulation technique simplifies the measurement of the phase currents and it eliminates the need of an external current sensor. The voltages of the Mosfets (T1, T2, T3) of the inverter lower side 28' can be used to measure the motor phase currents during all the sequences. In the case of the sequence T'1-T2, the voltage of transistor T2 is used to measure the motor phase current.

Fig 9 shows the control signals which are applied to the transistor gates in the case of the single switch modulation technique.

Fig 10 shows the current flow during one sequence in the motor operation mode. When transistors T'1 and T2 are switched "on" (Fig 10a), the battery supplies two phases 40 and 41 of the motor. When the transistor T'1 is switched "off", the structure diode of mosfet T1 is switched "on" and a free wheeling operation is occurring (Fig10b). The current ripple is reduced by half in comparison with the classical two-switch modulation technique. There is no current inversion in the DC bus and so the size of the filtering capacitor (not shown but well known in the art) can be reduced (lower RMS current on the DC bus). Consequently, the electromagnetic interferences are also lower than in the case of the classical modulation mode see the E.M.I. article referred herein.

Fig's 11 & 12 present the case of the generator operation mode. The upper side inverter transistors 29 T'1, T'2, T'3 are all switched "off" during the generator operation mode. Only the structure diodes of these transistors are used in this mode. A modulation signal is applied on the gate 42 of transistors T1, T2, T3 (see Fig. 6) in the lower side 28' of the inverter 28. There are some intervals where permanent conduction is occuring. They are used to measure the mosfet voltage for the current control (see Fig 12). Fig 12 shows the current flow during one sequence of operation. The machine or motor current increases when the transistors 30 T1, T2 are switched "on" (Fig 12b). When transistor T1 is switched "off", the structure diode of transistor T'1 is switched "on" and the machine supplies the battery 43 (Fig 12a).

Fig's 13 and 14 show block diagram views of a classical current regulation with a PI regulator 44 which can be applied in the case of the single switch modulation mode. The proposed electronic system for both motor and generator operation modes with the single switch modulation technique is presented on fig 15. This system includes two signal multiplexers and several AND/OR gates used to control the signals applied to the transistor driver stages and the signals of measurements of the machine current. The system is also realizable by an integrated circuit or a programmable circuit obvious to a person skilled in the art.

It is within the ambit of the present invention to cover any obvious modifications provided such modification fell within the scope of the appended claims.

Referring now to Figure 16 there is shown a brushless DC motor 50, constructed as above described, and wherein the rotor 51 is connected to a hub 52 of a wheel 53 herein a bicycle wheel. Alternatively, to reduce production cost, the motor cover housing may have connections to which the spokes of the wheel are connected to. A battery, not shown, is conveniently secured to the bicycle and power is fed to the control circuitry provided or mounted within the cavity inside the stator. A cable 54 is secured to a control device which is operated by the user of the bicycle to control the speed of the motor. This control device could be in the form of a rotating handle and grip, a hand lever device or any other convenient means. When the motor is used as a motorizing machine it drives the wheel 53. The motor can also be utilized as a break when placed in its generating mode. As previously mentioned, this motor can be secured to all sorts of electrical vehicles such as wheel chairs, scooters, tricycles, golf trolleys, small utility vehicles, etc.

We claim :

1. A brushless DC motor for electrical vehicle motorization comprising; a cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap therebetween, said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth, therebeing one coil per slots with predetermined connection patterns: A', C, C, B', B', A, A, C', C', B, B, and A' resulting in reduced torque ripple without any slot or magnet skewing.

2. A brushless DC motor for electrical vehicle motorization comprising; a cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap, therebetween said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth, therebeing two coils per slots with predetermined connection patterns: C', C, C', C, B, B', B, B', A', A, A', A, C, C', C, C', B', B, B', B, A, A', A, A' resulting in reduced torque ripple without any slot or magnet skewing.

3. A brushless DC motor as claimed in claim 1 or 2 having a multiple combination of additions of the number of said twenty-two poles and said twenty-four slots, such as forty-four said poles and forty-eight said slots, or sixty-six said poles and seventy-two said slots or ninety-six said poles and eighty-eight said slots; and a wound winding around said teeth with one of either one coil per slot or two coils per slot.

4. A brushless DC motor as claimed in claim 1 or 2 wherein three Hall sensors are mounted near said air gap at predetermined positions and fixed to or side some of said teeth.

5. A brushless DC motor as claimed in claim 4 having a power electronics pulse width modulation driver and control system, said pulse width modulation driver having a three phase inverter including six power mosfets, a current control system coupled to said inverter for generating 120 electrical degrees rectangular phase current pulses, said control system using a single switch modulation technique.

6. A brushless DC motor as claimed in claim 5 wherein said single switch modulation technique is comprised of three of said mosfets being connected as an upper side of said inverter and remain switched "on" by a modulation signal during a motor operation mode of said motor, three others of said mosfets being connected as a lower side of said inverter and used to measure motor phase currents during all sequences of the mosfets of said upper side.

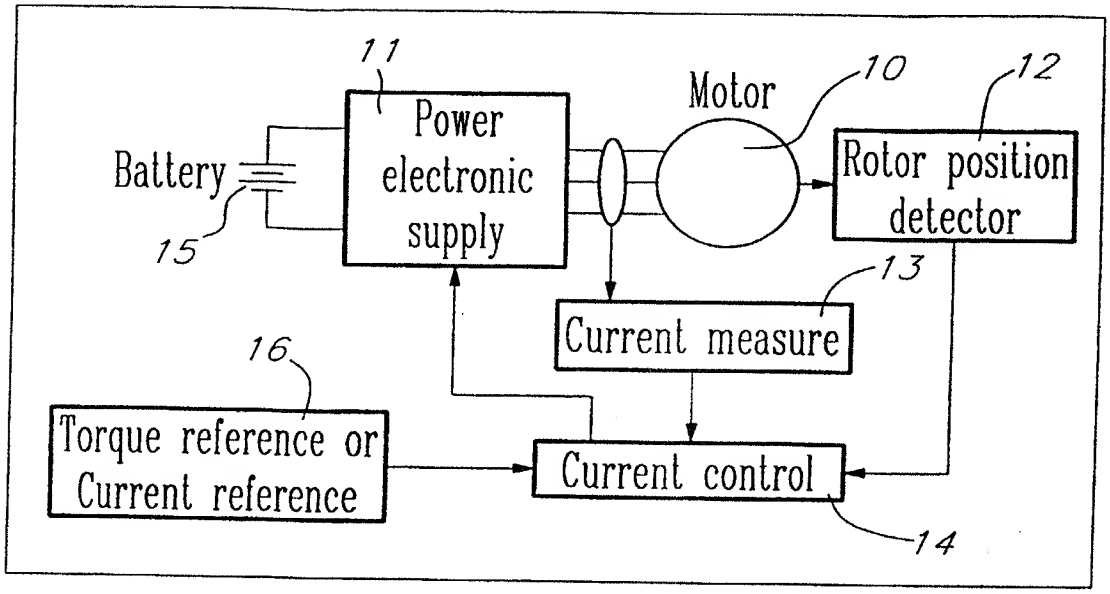
7. A brushless DC motor as claimed in claim 6 wherein said mosfets of said upper side of said inverter are switched "off" during a generator operation mode of said DC motor, and wherein a modulation signal is applied on a gate of said three mosfets on said lower side of said inverter.

8. A brushless DC motor as claimed in claim 1 wherein said motor is also used as a wheel braking device when used in a generator mode, said rotor being connected to a hub of a wheel powered by said motor when in a motorized mode.

9. A brushless DC motor electronic pulse width modulation driver and control system comprising: a power electronics three phase inverter having six power mosfets, a current control system coupled to said inverter for generating 120 electrical degrees rectangular phase current pulses, an electronic control system for both a motor and a generator operation mode of said motor and using a single switch modulation technique.

10. An electronic control system as claimed in claim 9 wherein voltages across thereof said mosfets on a lower side of said inverter are used to generate a current measurement for the purpose of motor current control of said single switch modulation technique.

11. A brushless DC motor for braking a wheel of devices on which people are displaced by self-motorization or electric motor motorization, said motor comprising a cylindrical rotor cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap, therebetween said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth said rotor being connected to a hub of said wheel, and control circuit means to control the torque of said motor and therefore its arresting force.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Power electronic supply
Motor
10
12
Rotor position detector
Battery
15
13
Current measure
16
Torque reference or Current reference
Current control
14

Fig. 1

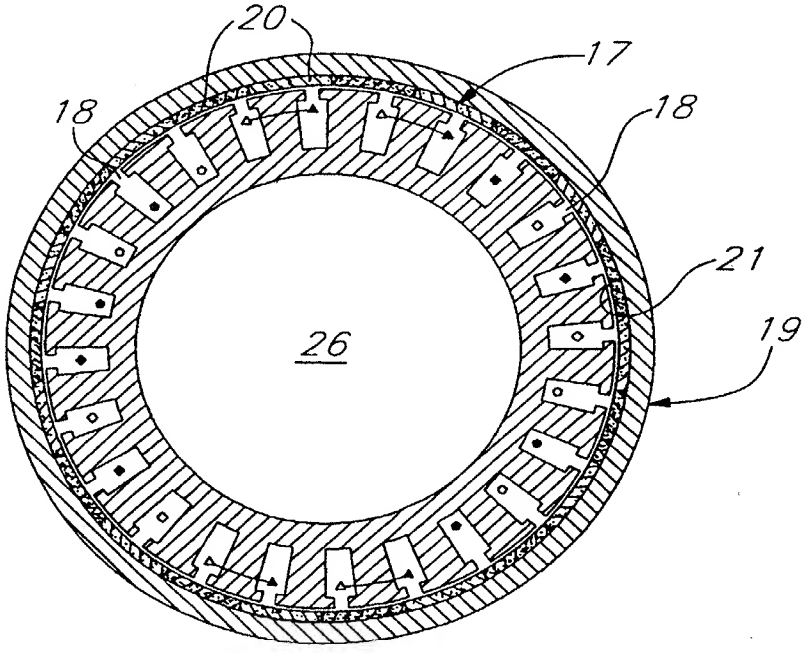
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Fig. 2

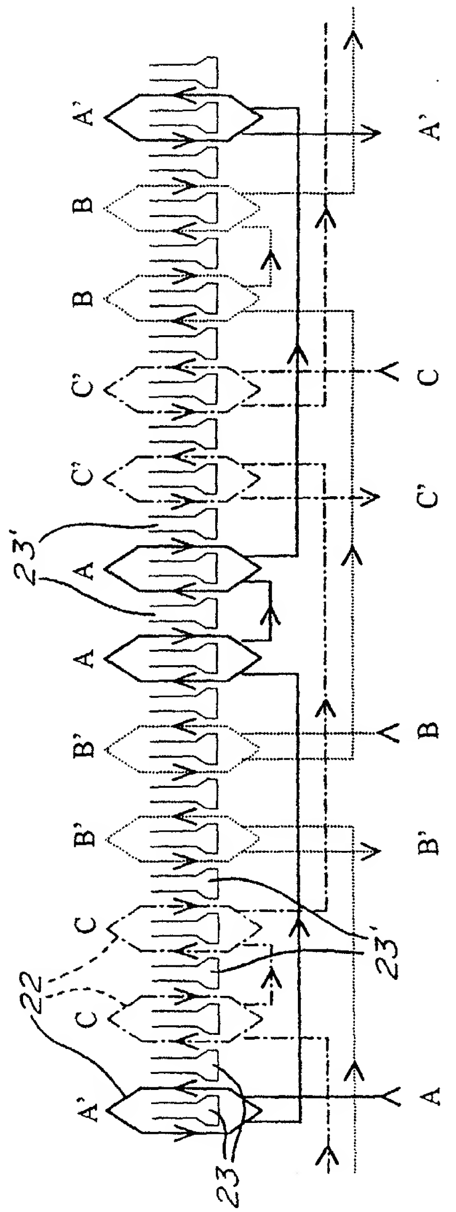

FIG. 3

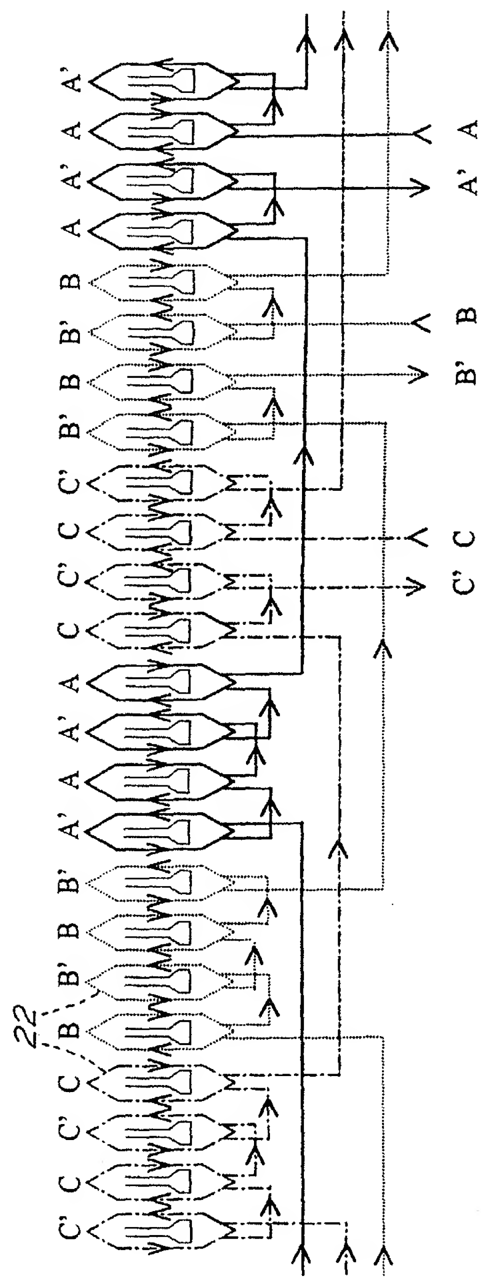

FIG. 4

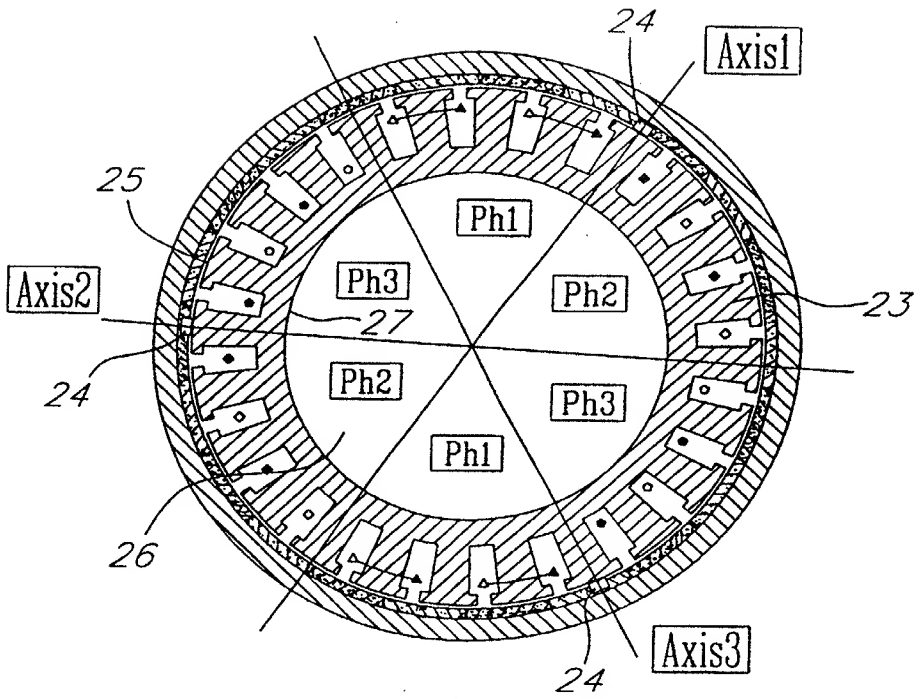

Fig - 5

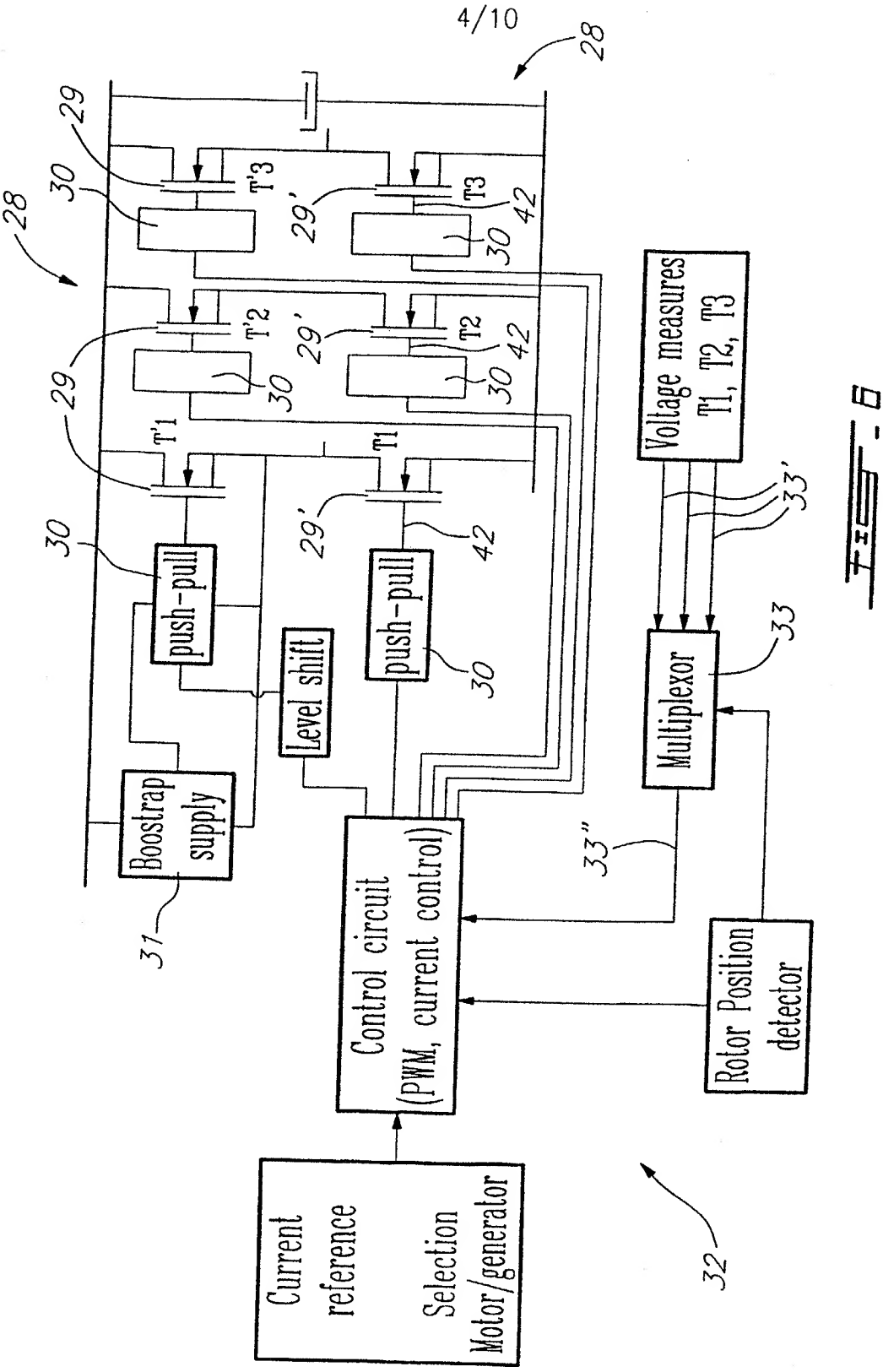
28
29
30
T'3
T3
29'
42
T'2
T2
T'1
T1
push-pull
Level shift
Boostrap supply
31
Voltage measures T1, T2, T3
33'
Multiplexor
33
33"
Control circuit (PWM, current control)
Rotor Position detector
Current reference
Selection Motor/generator
32

FIG - 8

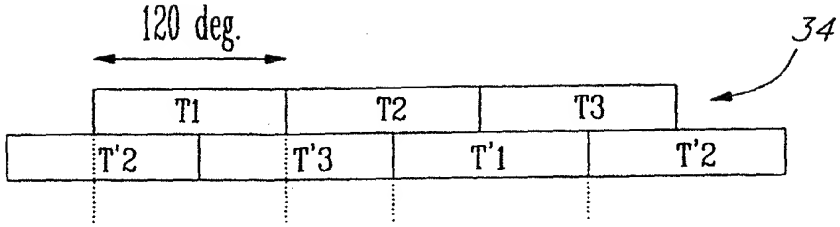

Fig 7

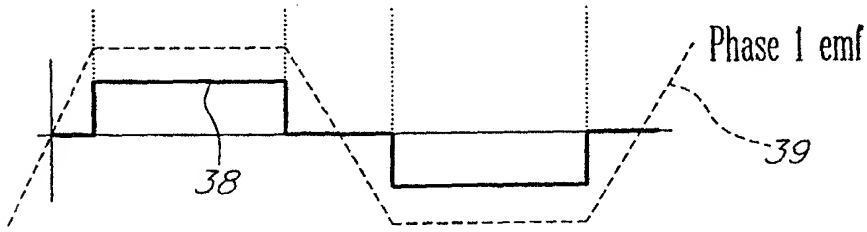

Fig 8

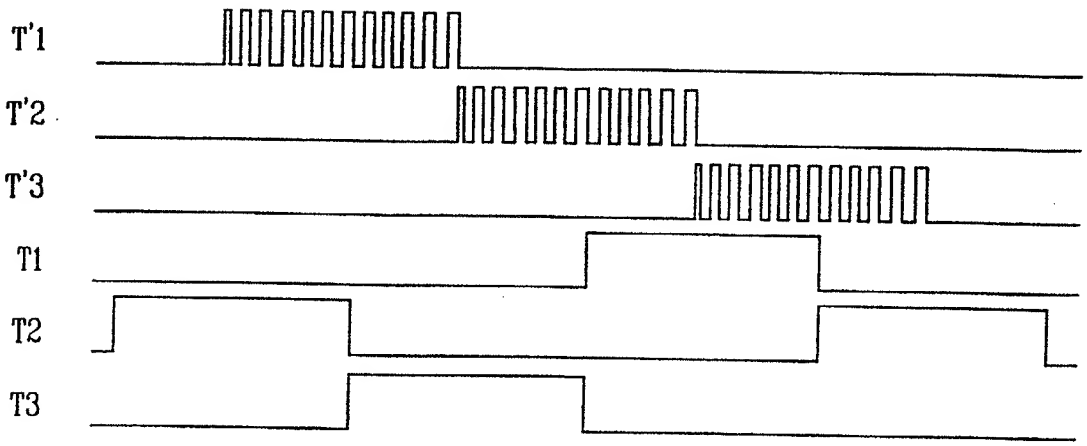

Fig 9

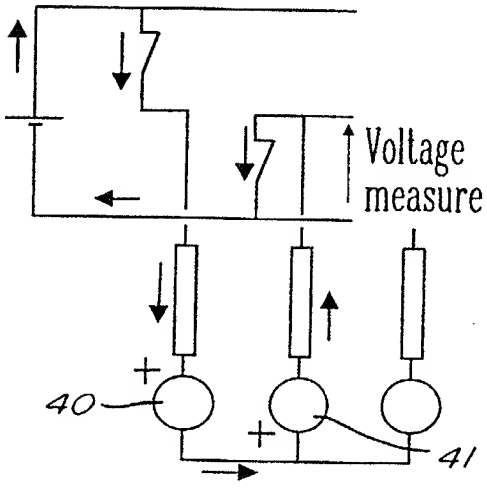

Fig 10a

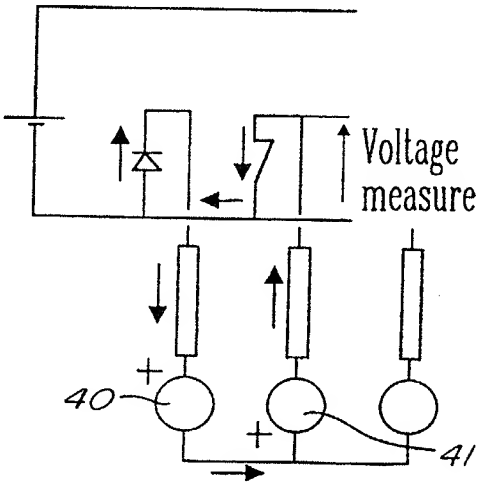

Fig 10b

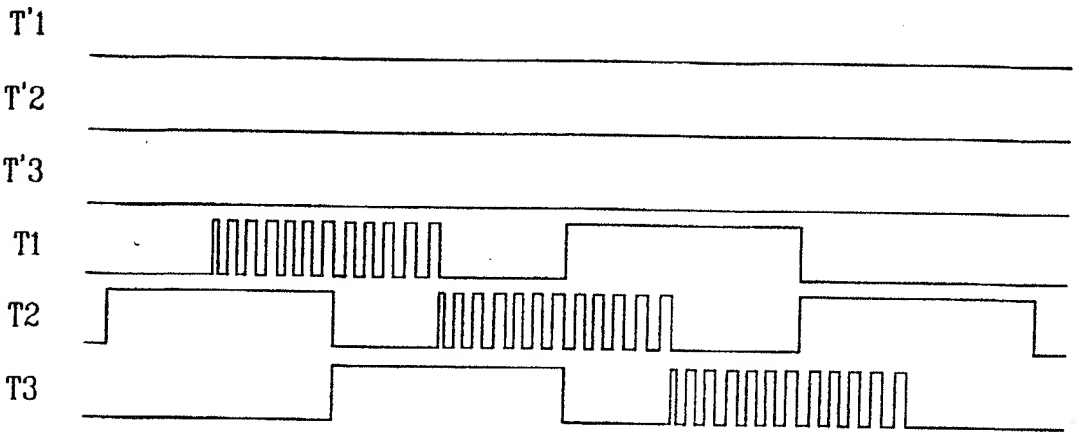

Fig - 11

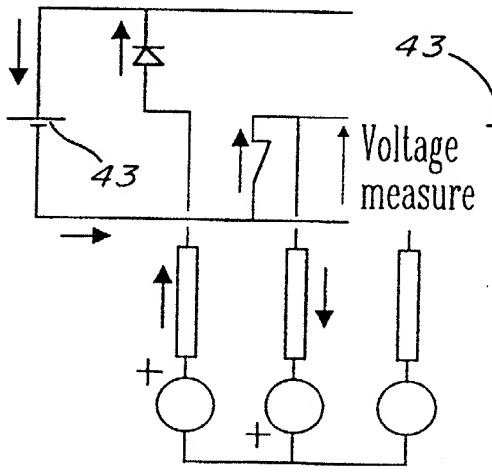

Fig - 12a

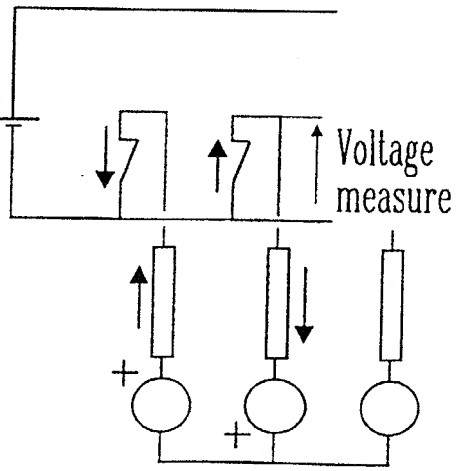

Fig - 12b

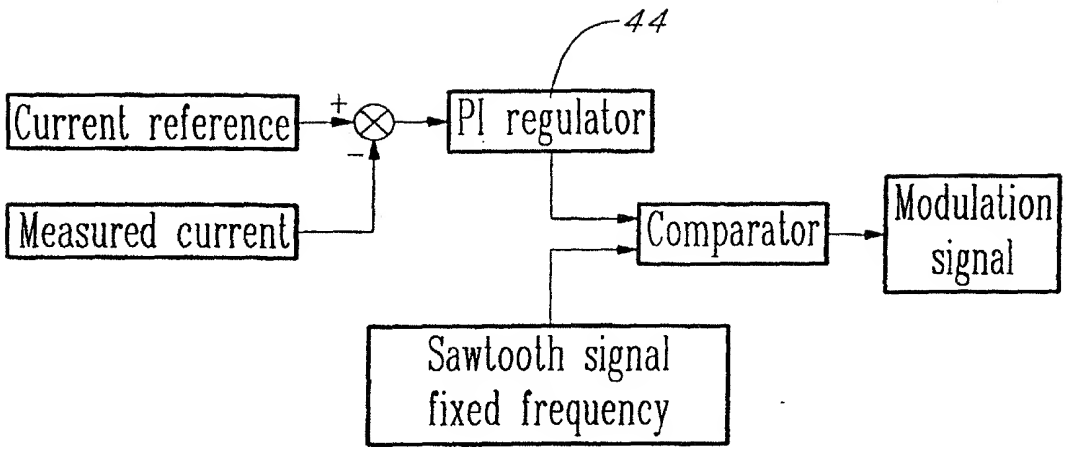
44
Current reference
+
−
PI regulator
Measured current
Comparator
Modulation signal
Sawtooth signal fixed frequency

Fig. 13

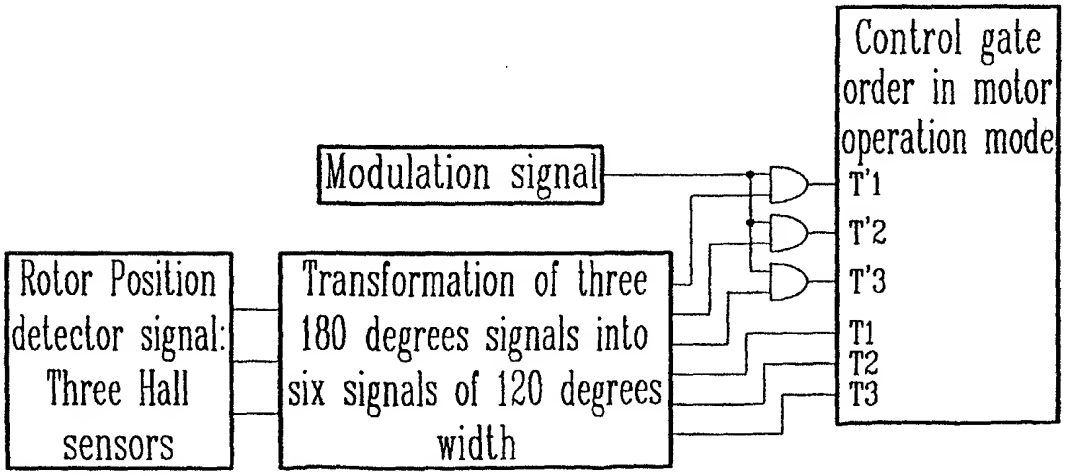
Control gate order in motor operation mode
Modulation signal
T'1
T'2
T'3
T1
T2
T3
Rotor Position detector signal: Three Hall sensors
Transformation of three 180 degrees signals into six signals of 120 degrees width

Fig. 14

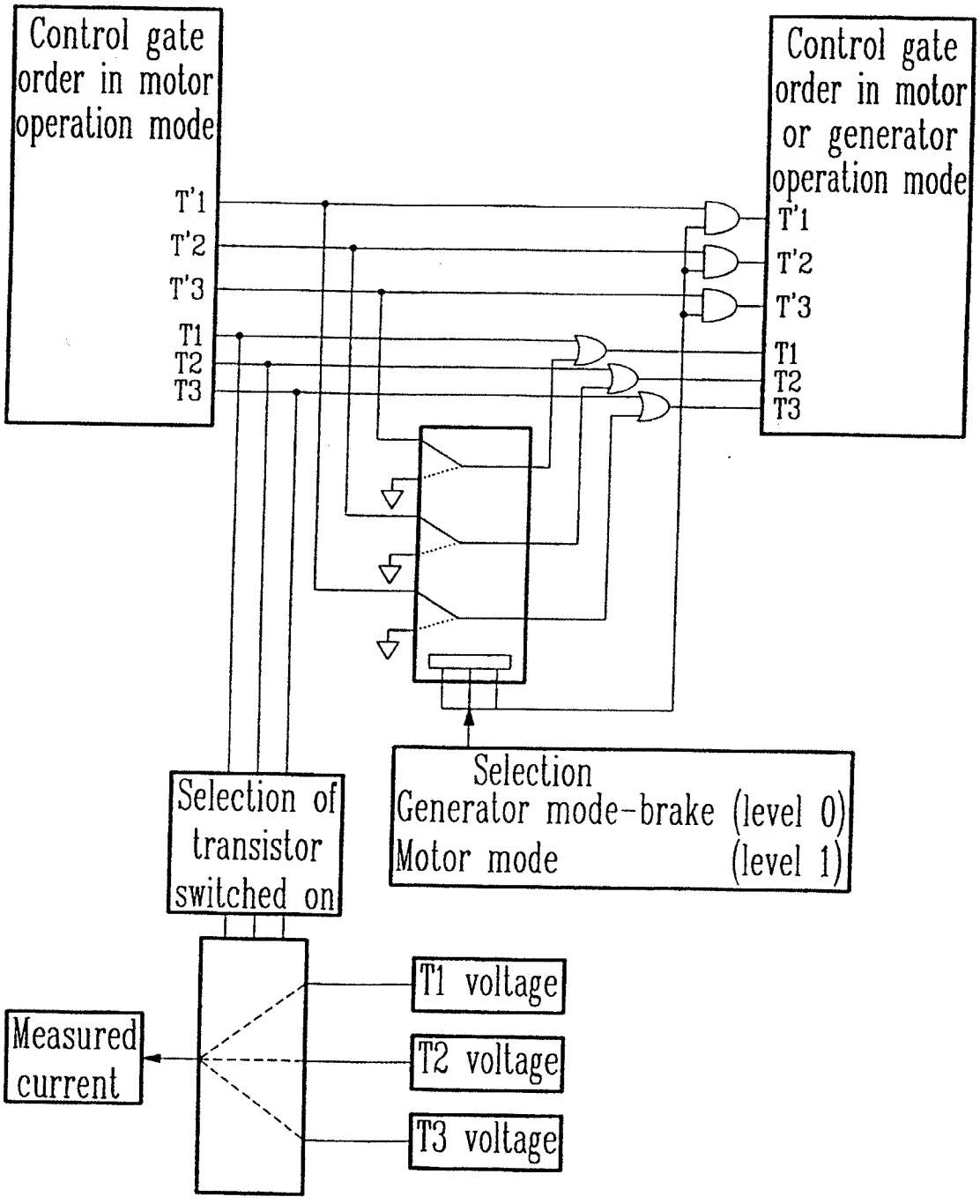
Control gate order in motor operation mode
T'1
T'2
T'3
T1
T2
T3
Control gate order in motor or generator operation mode
T'1
T'2
T'3
T1
T2
T3
Selection
Generator mode-brake (level 0)
Motor mode (level 1)
Selection of transistor switched on
T1 voltage
T2 voltage
T3 voltage
Measured current

Fig. 15

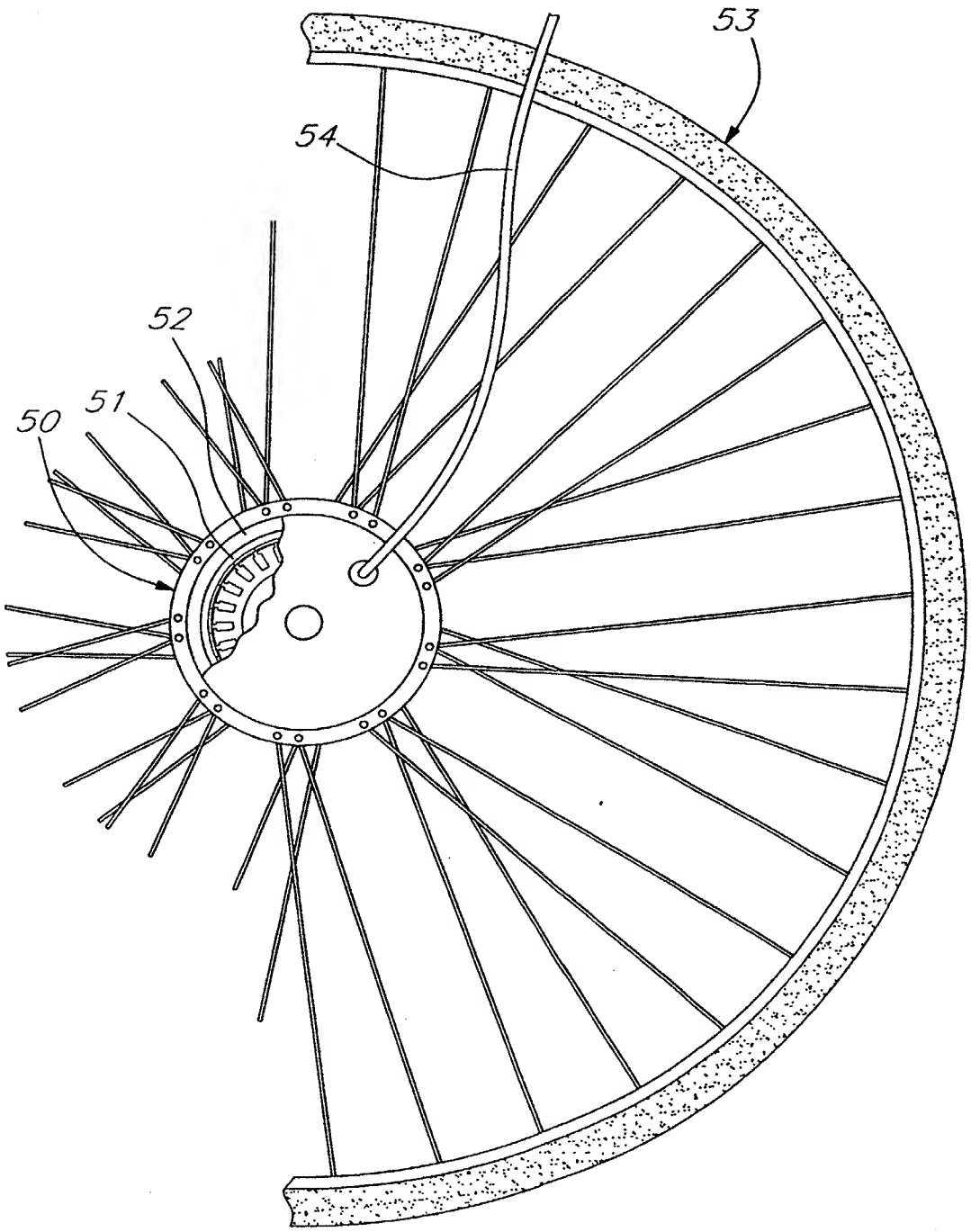

FIG - 16

INTERNATIONAL SEARCH REPORT

Inten Application No
PCT/CA 99/00290

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02K21/22 H02P6/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02K H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 5 006 745 A (NISHIO AKIRA ET AL) 9 April 1991 (1991-04-09) column 7, line 63 -column 8, line 9; claim 3; table 5 column 10, line 19 - line 35; claim 4; figure 7	2,3 5-8
X	US 5 164 622 A (KORDIK JEFFREY A) 17 November 1992 (1992-11-17) column 9, line 52 - line 53; figure 1 column 7, line 40 - line 47; figures 1,3	2-4
X	GB 2 289 991 A (CHAN CHING CHUEN) 6 December 1995 (1995-12-06) page 1, paragraph 3 - paragraph 4; figures 1A,2	1

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2000	27/01/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Roy, C

2

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter. Application No
PCT/CA 99/00290

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